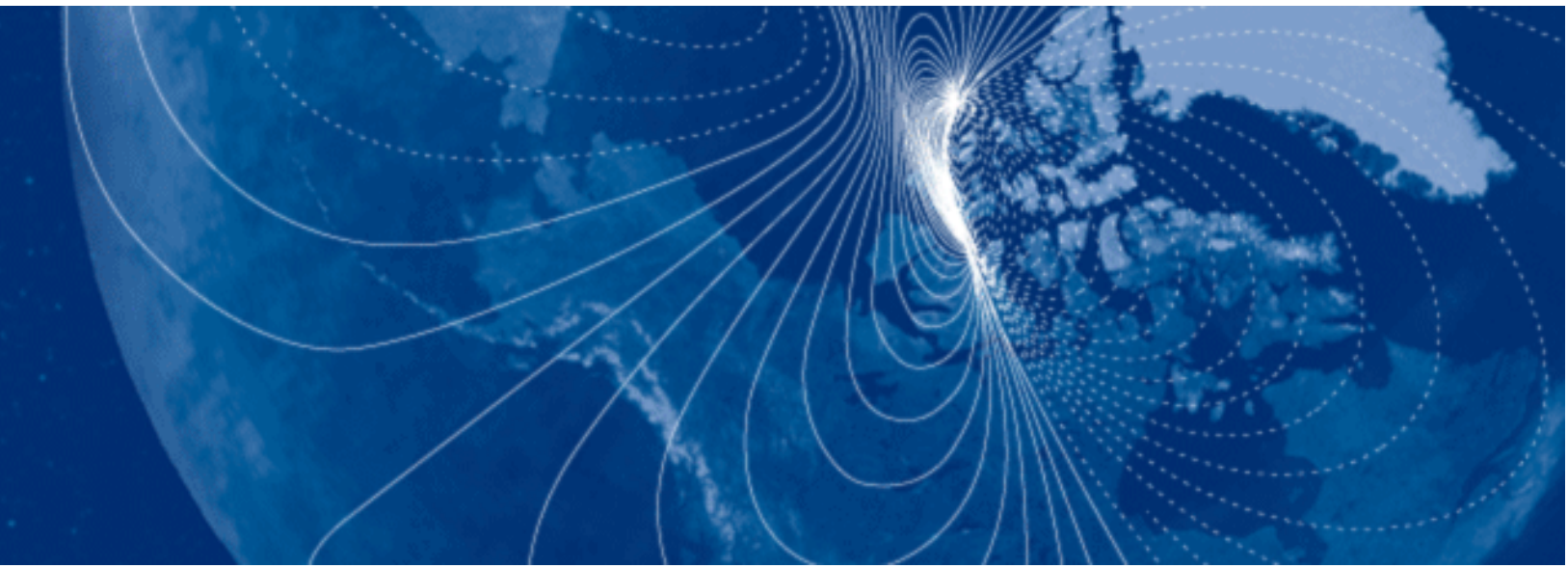

User Manual

CompassPoint® Prime

3-Axis Electronic Compass Module

PNI SENSOR CORPORATION

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1 Copyright & Warranty Information

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2 Introduction

Thank you for purchasing PNI's CompassPoint® Prime 3-axis electronic compassing module. Incorporating a 3-axis magnetic field sensing and 3-axis tilt sensing, the Prime provides accurate and precise tilt compensated heading measurements at up to 45° of tilt and at latitudes up to 85°. The Prime utilizes PNI's advanced magnetic distortion correction algorithms to provide accurate heading information when incorporated into a user's system, even when the compass is being tilted. With its small size, the Prime is capable of fitting into today's size sensitive systems. These advantages make PNI Sensor Corporation's Prime the choice for applications that require a low price with unmatched performance.

The Prime's advantages make it suitable for many applications, including:

- Sonobuoys
- Seismic monitoring systems
- Acoustic Doppler current profilers (ADCPs)
- Robotic systems

With its many potential applications, the Prime provides a command set designed with flexibility and adaptability in mind. Many parameters are user-programmable, including reporting units, a wide range of sampling configurations, output damping, and more. We hope the Prime will help you to achieve the greatest performance from your target system. Thank you for selecting the Prime.

3 Specifications

Table 3-1: Specifications[1]

Compass and Magnetometer Performance		
Heading	Range	360°
	Static Accuracy, tilt ≤45°	1° rms
	Resolution	0.1°
	Repeatability	±0.05°
Tilt (Pitch & Roll)	Range	±90° of pitch, ±180° of roll
	Static Accuracy	1° rms
	Resolution	0.1°
	Repeatability	0.05°
Maximum Dip Angle		85°
Magnetometers	Usable Field Range	±100 µT
	Resolution	0.05 µT
	Repeatability	0.1 µT

I/O Characteristics		
Communication Interface		Binary RS232
Communication Rate		300 to 115,200 baud
Maximum Sample Rate		10 samples/second
Maximum Receive Voltages		±30 V
Threshold Voltages	Receive Low	0.6 V maximum
	Receive High	2.4 V minimum
	Transmit Low[2]	-5.0V maximum
	Transmit High[2]	+5.0 V minimum
Time to Initial Good Data[3]	Initial power up	<180 ms
	Sleep mode recovery	<60 ms

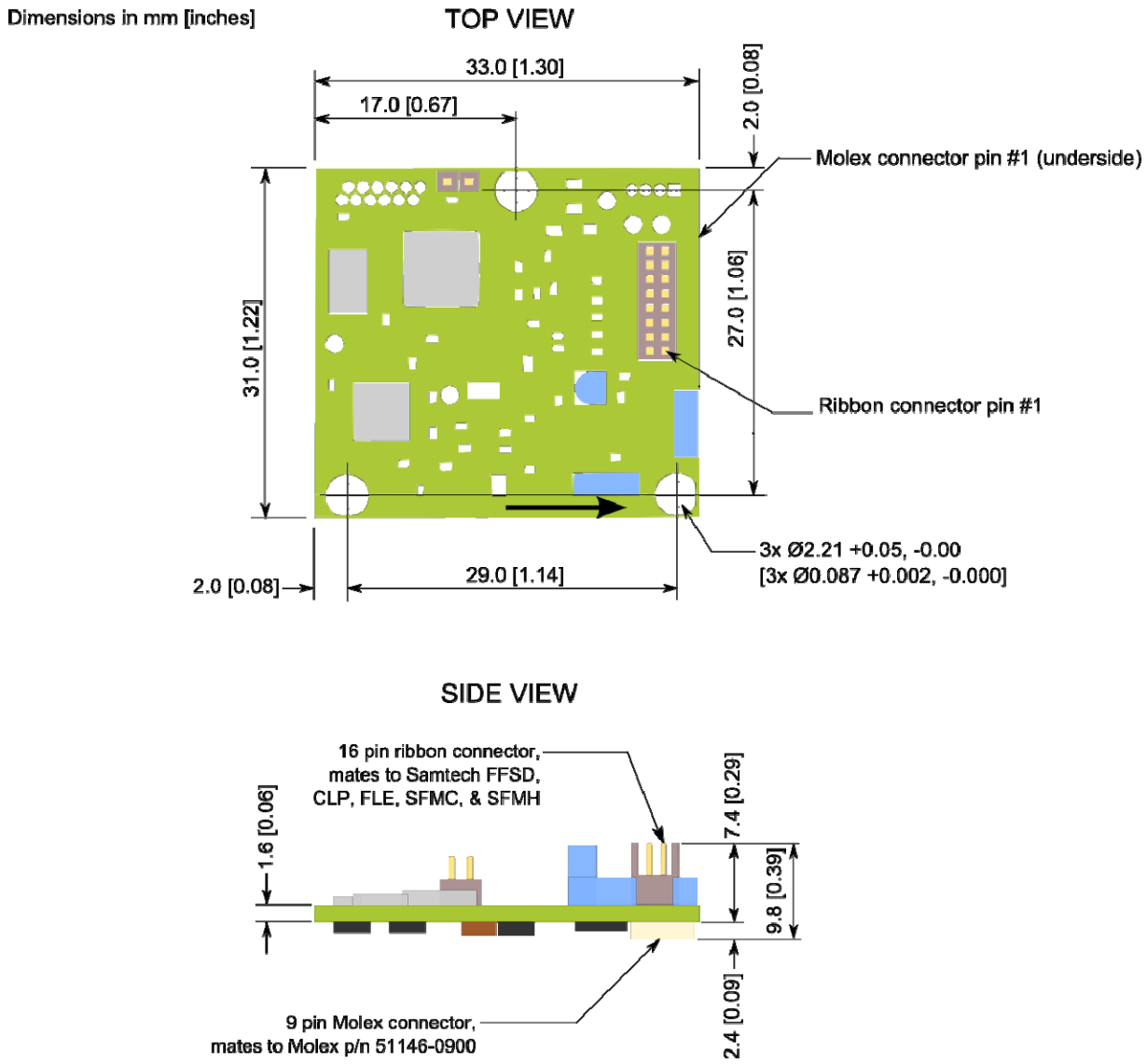
Mechanical Characteristics	
Dimensions (*l* x *w* x *h*)	3.3 x 3.1 x 1.3 cm (see Figure 3-1)
Weight	5 gm
Mounting Options	Screw mount / standoff, horizontal or vertical
Connector	16 pin ribbon or 9 pin Molex (Same functionality: use only one.)

Power Requirements		
DC Supply Voltage		3.6 - 5 V (unregulated)
Average Current Draw @ 10 Hz sample rate[4]		18 mA
Peak Current Draw[4]	During external power up	120 mA pk, 75 mA over 2 ms
	During logical power up/down	110 mA pk, 85 mA over 1 ms, 60 mA over 2 ms
Sleep Mode Current Draw		0.25 mA

Environmental Requirements	
Operating Temperature[5]	-40C to +85C
Storage Temperature	-40C to +85C

Notes on Specifications:

1. Specifications subject to change.
2. Transmit lines with 3k Ω load to ground.
3. FIR Taps set to 0.
4. Tested at 3.6V.
5. To meet performance specifications, recalibration may be necessary as the temperature varies across the operating range.



The default orientation for the Prime is for the silk-screened arrow to point in the “forward” direction.

Figure 3-1: Prime Mechanical Drawing

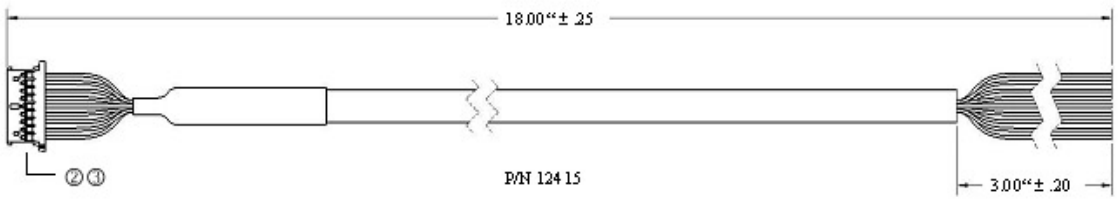


Figure 3-2: PNI Pigtailed Cable Drawing

4 Set-Up

This section describes how to configure, program, and control the Prime in your host system. To install the Prime into your system, follow these steps:

- Make electrical connections to the Prime
- Evaluate the Prime using the included StudioPrime Program
- Choose a mounting location
- Mechanically mount the Prime
- Perform user calibration

Before you install the module, it can be evaluated with the StudioPrime outside of your system. Please see Section 5.

4.1 Electrical Connections

The Prime incorporates both a 16 pin ribbon connector (topside of PCB) and a 9 pin Molex connector (bottomside of PCB) for connecting the unit to the user's system. The user should decide which connector they want to use, and only use this connector. The Prime will not function properly if commands are sent on both connectors.

The Prime Interface Kit includes the PNI 45 cm (18") custom pigtailed cable(see Figure 3-2). One end of the cable mates with the Prime's 9 pin Molex connector while the other end is not connectorized and has 9 wires accessible. These wires are intended to mate with the user's system. The cable's wires are color coded as indicated in Table 4-1.

The Prime Evaluation Kit includes the same PNI pigtailed cable as provided in the Interface Kit, plus a 1.8 m (6') custom dual-connectorized cable. This cable incorporates the Molex 51146-0900 connector on one end that mates to the Prime and a 9-pin sub-D connector on the other end to mate with a PC's serial port. This cable primarily is intended for basic evaluation of the Prime with a PC,

The pin-out for both connectors is given below in Table 4-1. Pin #1 for both connectors is indicated in Figure 3-1.

Table 4-1: Prime Pin Descriptions

Pin #	16 pin Ribbon Connector	9 pin Molex Connector	PNI Cable Wire Color
1	NC	GND	Black
2	DRDY	NC	Gray
3	GND	GND	Green
4	~CS	NC	Orange
5	GND	NC	Violet
6	MISO	NC	Brown
7	GND	RS232 TxD	Yellow
8	MOSI	RS232 RxD	Blue
9	GND	+5 VDC	Red
10	SCLK		
11	GND		
12	RS232 RxD		
13	GND		
14	RS232 TxD		
15	GND		
16	+5 VDC		

4.2 Where to Install

The Prime's wide dynamic range and sophisticated calibration algorithms allow it to operate in many environments. For optimal performance however, you should mount the Prime with the following considerations in mind:

4.2.1 Ensure operation in sensors' linear regime

The Prime can be field calibrated to correct for large static magnetic fields created by the host system. However, each axis of the Prime has a usable dynamic range of ±100 μT: if the total field exceeds this value for any axis the Prime may not give accurate heading information. When mounting the Prime, consider the effect of any sources of magnetic fields in the host environment that, when added to the earth's field, may take the sensors out of their linear regime. For example, problems can be caused by large masses of ferrous metals (such as transformers and vehicle chassis), large electric currents, permanent magnets, and electric motors.

4.2.2 Locate away from changing magnetic fields

It is not possible to calibrate for changing magnetic anomalies. For greatest accuracy, keep the Prime away from sources of local magnetic sources that can change

with time. Examples of such sources include electrical equipment that will be turned on and off, or ferrous bodies that will move. Make sure the Prime is not mounted close to cargo or payload areas that may be loaded with large sources of local magnetic fields.

4.2.3 Mount in a physically stable location

Choose a location that is isolated from excessive shock, oscillation, and vibration.

4.2.4 Preliminary testing

Testing should be performed at an early stage of development to understand and accommodate the magnetic distortion contributors in a host system. Use the data logger in StudioPrime, as discussed in Section 5.6, to perform the following tests.

- Determine the distance range of field distortion. Place the compass in a fixed position, then move or energize suspect components while observing the output to determine when they are an influence.
- Determine if the mounting location's magnetic field is within the l range of the compass. With the compass mounted, rotate and tilt the system in as many positions as possible. While doing so, monitor the magnetometer outputs, observing if the maximum linear range is exceeded.

4.3 Mechanical Mounting

Refer to Figure 3-1 for the Prime's dimensions, mounting holes, and the orientation of the reference frame.

The Prime is pre-loaded with calibration coefficients so it nominally indicates north per the arrow on the PCB, assuming a standard orientation (STD 0°) and minimal local magnetic distortions. To meet specifications it will be necessary for the user to calibrate the Prime.

The Prime can be mounted in various orientations. All reference points are based on the white silk-screened arrow on the top side of the board. Note, however, that StudioPrime only supports 6 of the mounting configurations, as discussed in Section 5.3.1 and depicted in Figure 4-1.

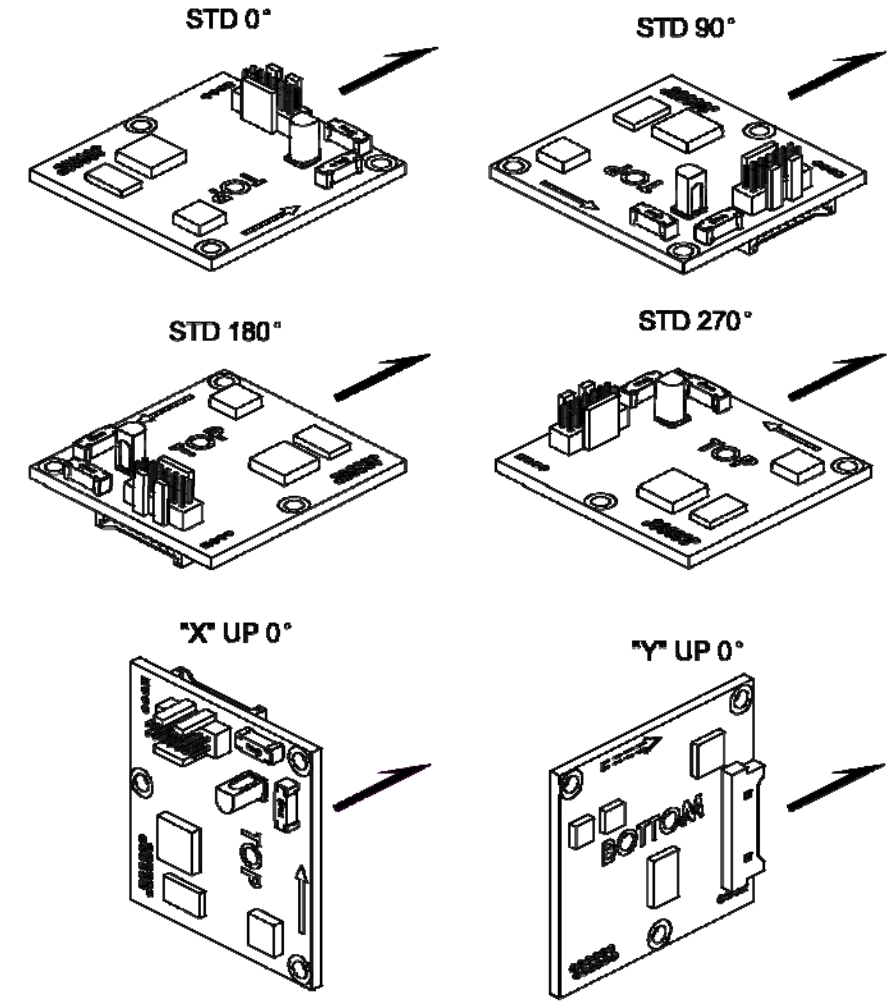


Figure 4-1: Prime Typical Mounting Orientations

5 Operation with StudioPrime

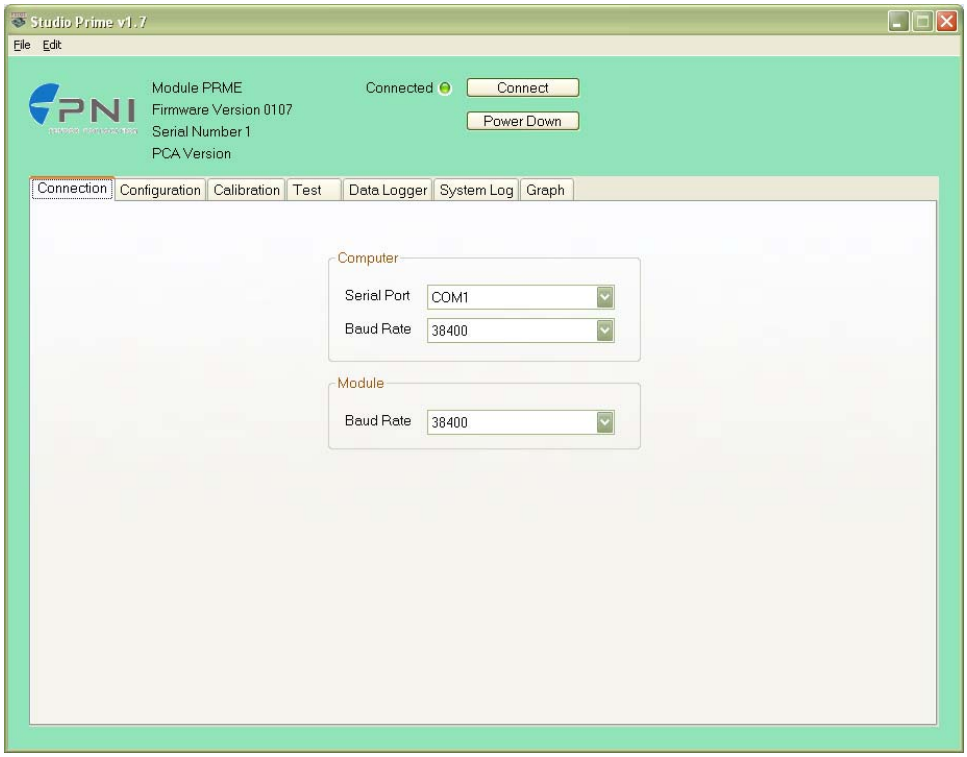
The StudioPrime evaluation software communicates with the Prime through the COM port (serial port) of your PC. It puts an easy-to-use, graphical-user interface (GUI) onto the binary command language used by the Prime. Instead of manually issuing command codes, the user can use buttons, check boxes, and dialog boxes to control the Prime and obtain data. It reads the binary responses of the Prime output and formats this into labeled and easy-to-read data fields. StudioPrime also includes the ability to log and save the outputs of the Prime to a file. All this allows the user to begin understanding the capabilities of the Prime while using StudioPrime's friendly interface. Check PNI's website (www.pnicorp.com) for the latest version.

5.1 Installation onto a Windows or Mac system

StudioPrime is provided as an executable program which can be downloaded from PNI's website. It will work with Windows 98, Windows ME, Windows 2000, Windows XP, Windows Vista, and Mac OS X operating systems. Please check the PNI web page at www.pnicorp.com for the latest version.

Copy StudioPrime to your computer, then launch it by double clicking on the icon. Follow the installation instructions as prompted.

5.2 Connection Tab



5.2.1 Initial connection

- Ensure well-charged batteries are installed into the PNI evaluation cable and the cable is securely attached to the Prime and the PC's serial port.
- Select the serial port the unit is plugged into, which is usually COM 1.
- Select 38400 as the baud rate.
- Click on the <Connect> button.
- Once a connection is made the "Connected" light will turn green and the module type, firmware version and serial number will be displayed.

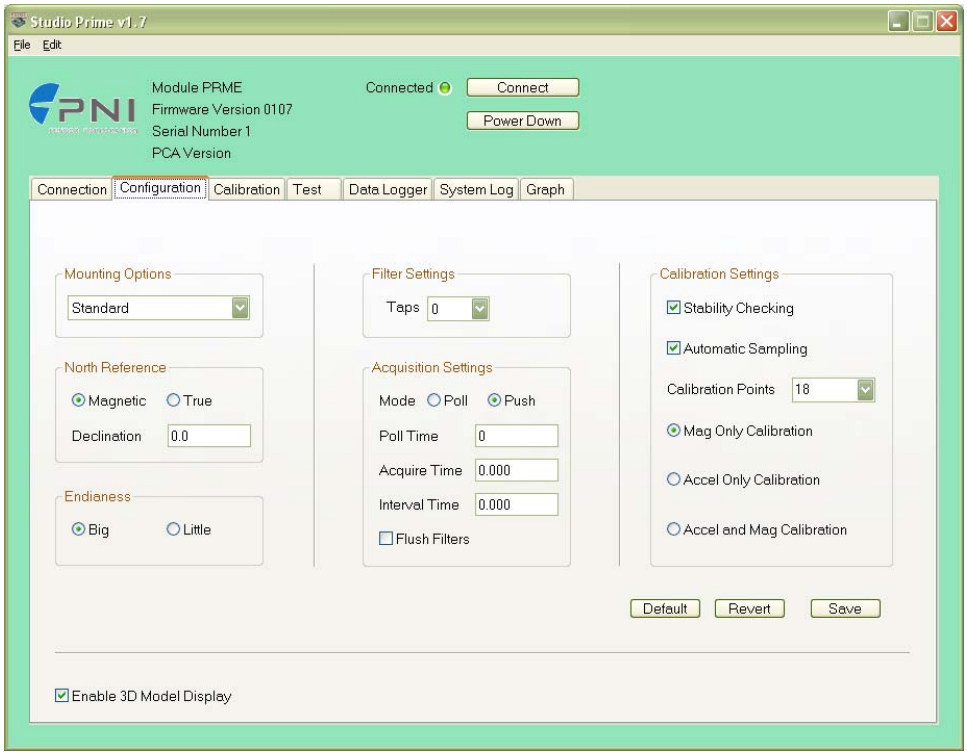
5.2.2 Changing baud rate

- Select the desired baud rate for the module.
- Click on the <Power Down> button.
- Select same baud rate for the computer.
- Click on the <Power Up> button.

5.2.3 Changing modules

Once a connection has been made, StudioPrime will recall the last settings. If a different module is used, click the <Connect> button once the new module is attached. This will reestablish a connection assuming the baud rate is unchanged.

5.3 Configuration Tab



Note: No settings will be changed in the unit until the <SAVE> button has been selected.

5.3.1 Mounting Options

StudioPrime supports 6 mounting orientations, as detailed below. Refer to Figure 4-1 for a drawing illustrating each orientation. (The description in parentheses matches Figure 4-1, while the initial description matches StudioPrime.) Note that the RS232 interface supports 18 additional (24 total) orientations.

Standard (STD 0°)

When selected the unit is to be mounted with the main board in a horizontal position (the Z axis magnetic sensor is vertical).

Standard 90 Degrees (STD 90°)

When selected the unit is to be mounted with the main board in a horizontal position but rotated so the arrow is pointed 90 degrees clockwise from the front of the host system.

Standard 180 Degrees (STD 180°)

When selected the unit is to be mounted with the main board in a horizontal position but rotated so the arrow is pointed 180 degrees from the front of the host system.

Standard 270 Degrees (STD 270°)

When selected the unit is to be mounted with the main board in a horizontal

position but rotated so the arrow is pointed 270 degrees clockwise from the front of the host system.

X Sensor Up ("X" Up 0°)

When selected the unit is to be mounted with the main board in a vertical position (the X axis magnetic sensor is vertical).

Y Sensor Up ("Y" Up 0°)

When selected the unit is to be mounted with the main board in a vertical position (the Y axis magnetic sensor is vertical).

5.3.2 North Reference

Magnetic

When the "Magnetic" radio button is selected, heading will be relative to Magnetic North.

True

When the "True" radio button is selected, heading will be relative to True North. To use North Heading in "True" mode, the declination needs to be set in the "Declination" window. Refer to Section 6.3 for more information.

5.3.3 Endianess

Use to select either Big Endian or Little Endian; default is Big Endian. See Section 7.2 for more information on appropriate data formats.

5.3.4 Filter Setting (Taps)

The Prime incorporates a finite impulse response (FIR) filter to effectively provide a more stable heading reading. The number of taps (or samples) represents the amount of filtering to be performed. The user should select either 0, 4, 8, 16, or 32 taps, with zero taps representing no filtering. Note that selecting a larger number of taps can significantly slow the time for the initial sample reading and, if "Flush Filters" is selected, the rate at which data is output. The default setting is 8 taps.

5.3.5 Acquisition Settings

Mode

- "Poll" mode should be selected when the host system will poll the Prime for data. StudioPRIME allows the user to simulate this on their PC. In this case, StudioPRIME requests data from the Prime module at a relatively fixed basis.
- "Push" mode should be selected if the user will have the Prime output data at a relatively fixed rate to the host system. In this case the Prime module is pushing data out to StudioPRIME at a relatively fixed rate.

Poll Delay

The Poll Delay is relevant when Poll Mode is selected, and is the time delay, in

seconds, between the completion of StudioPRIME receiving one set of sampled data and requesting the next sample set. If the time is set to 0 then StudioPRIME requests new data as soon as the previous request has been fulfilled. Note that the inverse of the Poll Delay is somewhat greater than the sample rate, since the Poll Delay does not include actual acquisition time.

Interval Delay

The Interval Delay is relevant when Push Mode is selected, and is the time delay, in seconds, between completion of the Prime module sending one set of sampled data and the start of sending the next sample set. If the time is set to 0 then the Prime will begin sending new data as soon as the previous data set has been sent. Note that the inverse of the Interval Delay is somewhat greater than the sample rate, since the Interval Delay does not include actual acquisition time.

Acquire Delay

The Acquire Delay sets the time between samples taken by the module, in seconds. This is an internal setting that is NOT tied to the time with which the module transmits data to StudioPRIME or the host system. Generally speaking, the Acquire Delay is either set to 0, in which case the Prime is constantly sampling or set to equal either the Poll Delay or Interval Delay values. The advantage of running with an Acquire Delay of 0 is that the FIR filter can run with a relatively high Tap value to provide stable and timely data. The advantage of using a greater Acquire Delay is that power consumption can be reduced, assuming the Interval or Poll Delay are no less than the Acquire Delay.

Flush Filters

The filtering is set to only update the filter with the last sample taken, for example once the initial 8 samples are taken (assuming Taps is set to the default value of 8) any new sample is added to the end with the first sample being dropped. In the case where the “Acquire Time” is set to a value it would be prudent to set the unit to flush the filter prior to calculating the heading. This flushing will require the unit to take 8 new samples to use for the calculation.

Note: If “Flush Filters” is checked, it will take longer for the unit to output updated data.

5.3.6 Calibration Settings

The Prime supports both magnetometer and accelerometer calibration. These calibrations can be performed independently or simultaneously. The relevant StudioPrime inputs for these calibrations are discussed below. See Section 6.2 for information on how to perform a calibration.

Stability Checking

By default the unit will wait for the readings to be stable for 3 consecutive readings when in calibration mode prior to saving the sample for use in the calibration. This is why the unit must be held steady between points during the User Calibration. This stability helps to ensure a proper heading and allow for higher accuracy, but it also takes more time. If the user de-selects the check box, then the unit will NOT wait for a stable reading and instead take a reading once the minimum change between points threshold has been met.

Automatic Sampling

When selected, the unit will take a point once the minimum change requirement and the stability check requirement (if selected) have been satisfied. If the user wants more control over when a point will be taken, then Automatic Sampling should be deselected. Once deselected, the <Take Sample> button on the Calibration tab will be active. Clicking on the <Take Sample> button will indicate to the unit to take a sample once the minimum requirements are met.

Calibration Points

The user can select the number of points to take during a calibration. A minimum of 12 sample points are needed for a successful magnetometer calibration, while 18 samples are recommended for either accelerometer-only calibration or simultaneous magnetometer and accelerometer calibration.

Mag Only Calibration

Select this when only magnetometer calibration will be performed.

Accel Only Calibration

Select this when only an accelerometer calibration will be performed.

Accel and Mag Calibration

Select this when magnetometer and accelerometer calibrations will be performed simultaneously.

Enable 3D Model

This box is located in the lower left corner of the window, and checking the box enables StudioPrime's live-action 3-D rendering of a helicopter, shown on the Test tab. The default is for the 3D model to be enabled (box checked), but some computer systems may not have the graphics capability to render this model, and it may be necessary to turn off this feature.

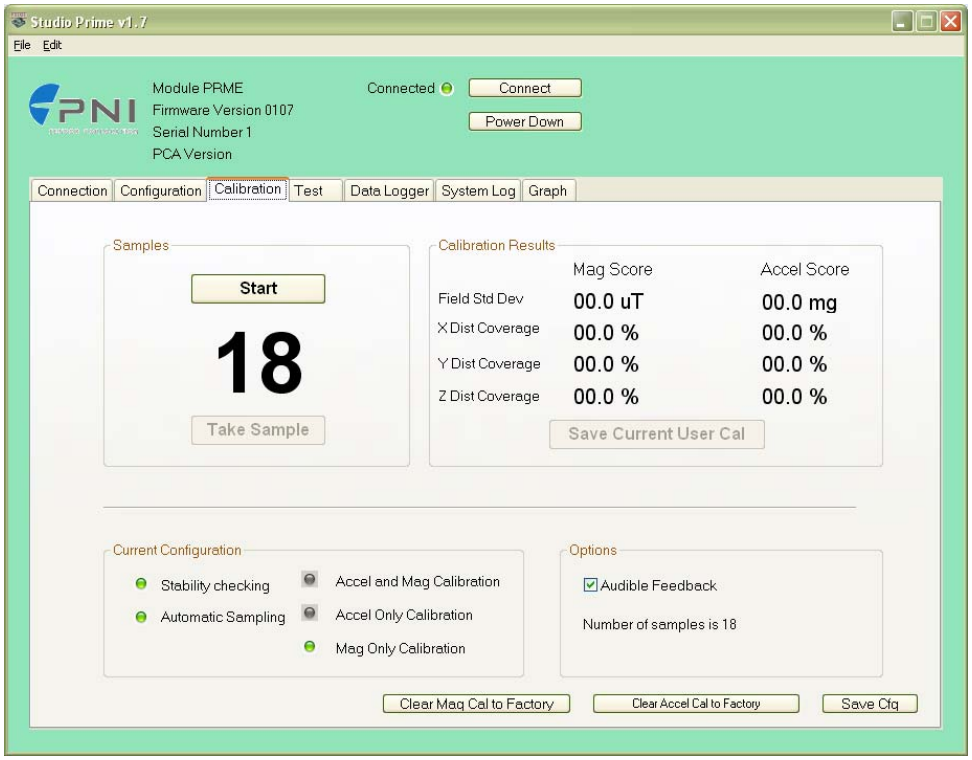
5.3.7 Default

Clicking this button reverts the StudioPrime program to the factory default settings.

5.3.8 Revert

This button will have the StudioPrime program read the settings from the unit and display them on the screen.

5.4 Calibration Tab



5.4.1 Samples

Clicking on the <Start> button begins the calibration process.

To take a sample point, the unit will need to be held steady for a short time. Assuming Automatic Sampling is selected (set on the Configuration tab), the window will indicate when the sample has been taken by incrementing the sample number. At this point, the module's orientation should be changed and held steady for the next sample. Once the pre-set number of samples has been taken (set on the Configuration tab) the calibration is complete. Refer to Section 6 for the recommended calibration points for each calibration method.

5.4.2 Calibration Results

Once calibration is complete the "Calibration Results" window will indicate the quality of the calibration. This applies to both magnetometer and accelerometer calibration. The X, Y, and Z "Dist Coverage" values show a percentage of each vector that has been covered during the calibration. The only way to get a Z value greater than 50% would be to take some points with the unit upside-down. The "Field Std Dev" values for Mag

Score and Accel Score indicate the overall quality of the calibration. The “Field Std Dev” Mag Score should be <0.1 and the Accel Score value should be <2. If a better score is needed, click on the <Start> button to begin a new calibration. See Section 6.2 for additional information.

If a Mag Only Calibration is performed, the Mag Score will reflect the new magnetometer calibration, while the Accel Score will be grayed out and represent the last saved Accel Score values. Similarly, if an Accel Only Calibration is performed the Accel Score will reflect the new accelerometer calibration and the Mag Score will be grayed out and reflect the last saved Mag Score values.

If the <Stop> button is clicked during a calibration process prior to taking 12 samples, this will abort the calibration. (The <Start> button turns into the <Stop> button once the calibration process is started.) The scores associated with the calibration method that was aborted will be -1, while scores unassociated with the aborted calibration method will be grayed out and represent their last saved values.

If the calibration is acceptable, then click the <Save Current User Cal> button to save the calibration. If this button is not selected then the unit will need to be recalibrated after a power cycle.

Note: The values in μT or mg refer to the quality of the calibration and NOT the accuracy of the heading. It is possible to have a good calibration but poor accuracy if the magnetic field the unit is exposed to during calibration changes after calibration.

5.4.3 Current Configuration

These indicators mimic the pertinent selections made on the Configuration tab.

5.4.4 Options

Audible Feedback:

If selected, StudioPrime gives an audible signal when a calibration point is taken. Note that an audible signal also will occur when the <Start> button is clicked, but no data will be taken.

5.4.5 Clear

Clear Mag Cal to Factory:

This button clears the user’s calibration of the magnetometers. Once selected, the unit reverts to its factory magnetometer calibration. To save the “Clear” in non-volatile memory, click the <Save Cfg > button.

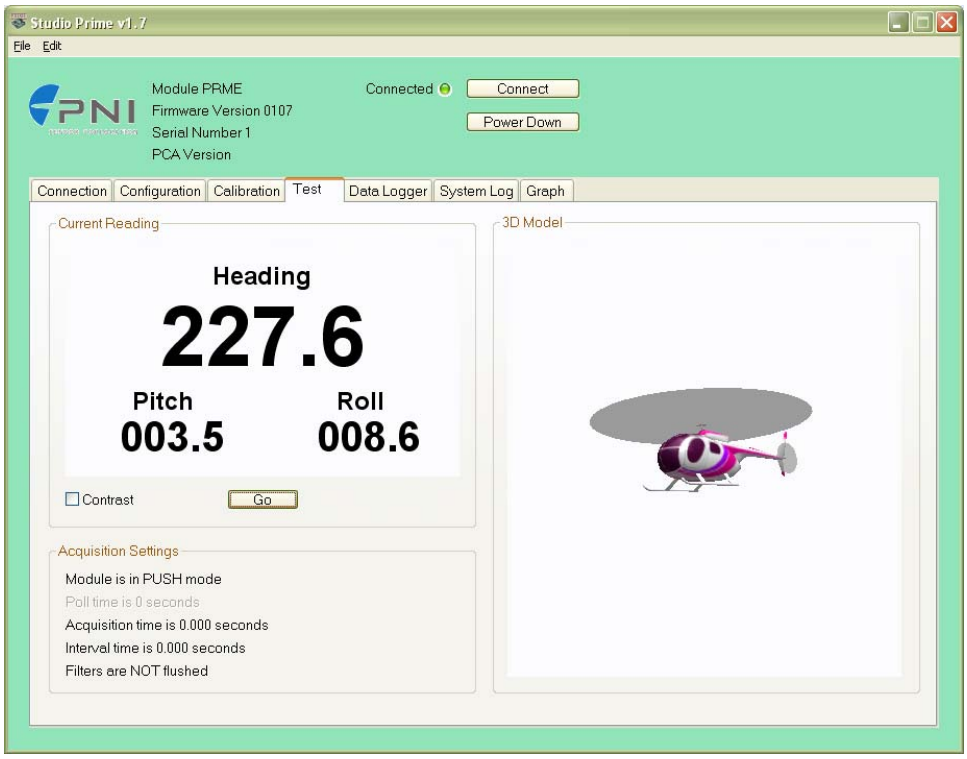
Clear Accel Cal to Factory:

This button clears the user's calibration of the accelerometers. Once selected, the unit reverts back to its factory accelerometer calibration. To save the "Clear" in non-volatile memory, click the <Save Cfg> button.

Save Cfg:

This button is only used in conjunction with either of the two buttons detailed above.

5.5 Test Tab



5.5.1 Current Reading

Once the <GO> button is selected the unit will begin outputting Heading, Pitch and Roll information. Selecting the <Stop> button or changing tabs will halt the output of the unit.

Contrast

Selecting this box sets the "Current Readings" window to have yellow lettering on a black background, rather than black lettering on a white background.

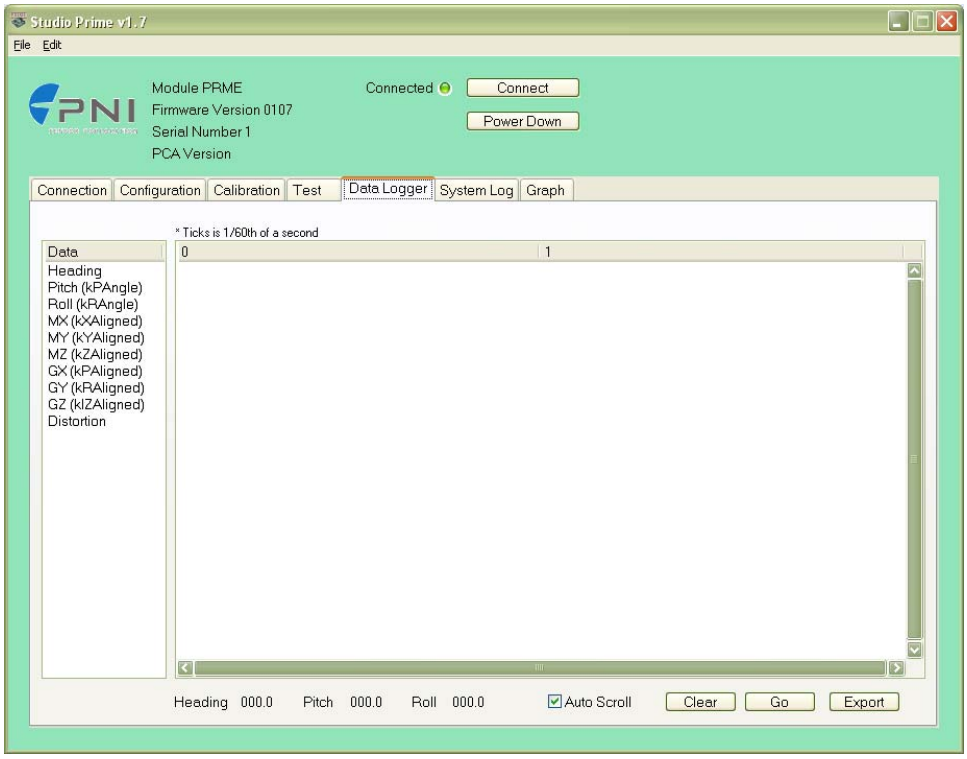
5.5.2 Acquisition Settings

These indicators mimic the pertinent selections made on the Configuration tab.

5.5.3 3D Model

The helicopter will follow the movement of the attached module and give a visual representation of the module's orientation, assuming the "Enable 3D Model Display" box is selected on the Configuration tab.

5.6 Data Logger Tab

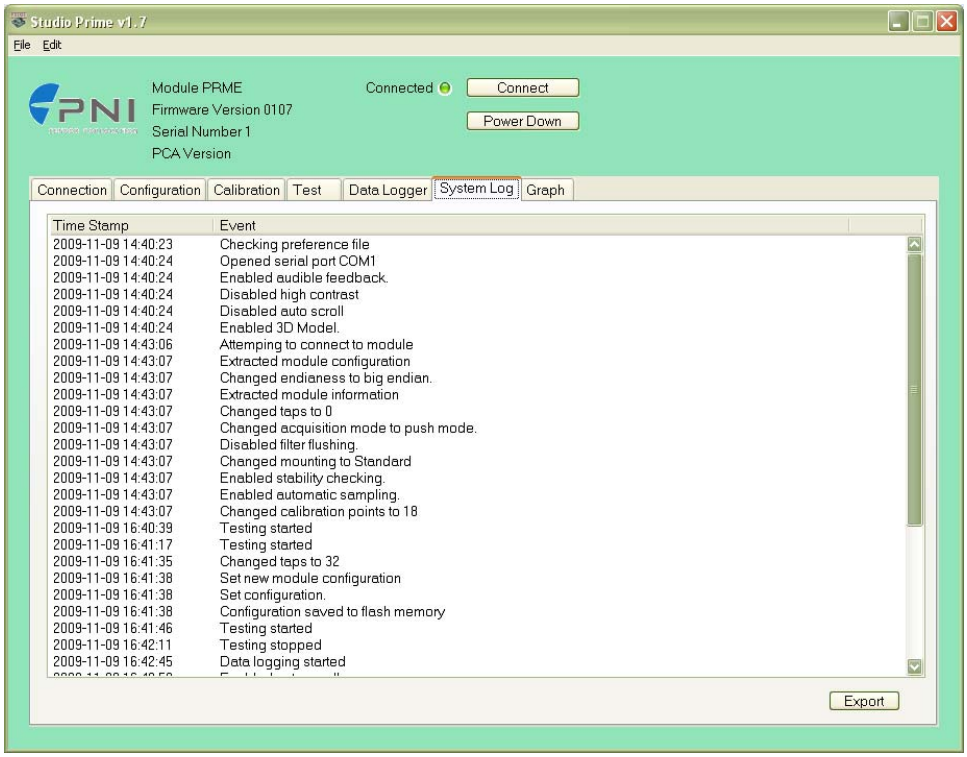


StudioPrime can capture measurement data and then export it to a text file. To acquire data and export it, follow the procedure below:

- Select the data to log in the "Data" window.
- Use Shift-Ctrl-Click and Ctrl-Click to select multiple items.
- Click on the <GO> button to start logging; click the <STOP> button to stop logging.
- Click on the <Export> button to save the data to a file.
- Click on the <Clear> button to clear the data from the window.

Note: The data logger use ticks for time reference. A tick is 1/60 second.

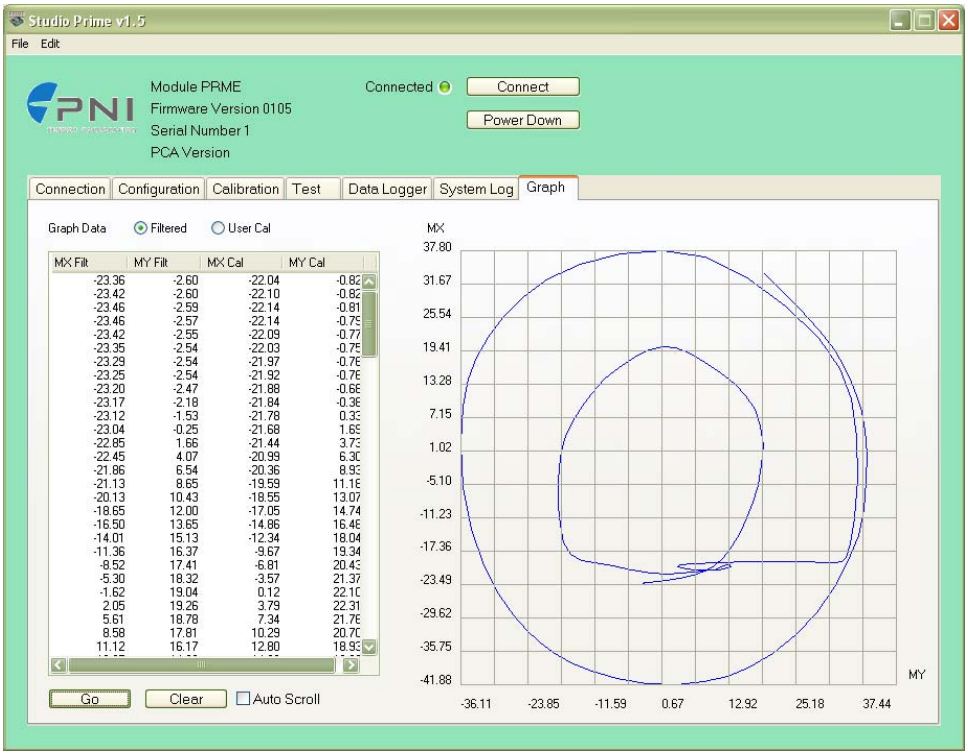
5.7 System Log Tab


Studio Prime v1.7
File Edit
Module PRME
Firmware Version 0107
Serial Number 1
PCA Version
Connected
Connect
Power Down
Connection Configuration Calibration Test Data Logger System Log Graph
Time Stamp Event
2009-11-09 14:40:23 Checking preference file
2009-11-09 14:40:24 Opened serial port COM1
2009-11-09 14:40:24 Enabled audible feedback.
2009-11-09 14:40:24 Disabled high contrast
2009-11-09 14:40:24 Disabled auto scroll
2009-11-09 14:40:24 Enabled 3D Model.
2009-11-09 14:43:06 Attemping to connect to module
2009-11-09 14:43:07 Extracted module configuration
2009-11-09 14:43:07 Changed endianess to big endian.
2009-11-09 14:43:07 Extracted module information
2009-11-09 14:43:07 Changed taps to 0
2009-11-09 14:43:07 Changed acquisition mode to push mode.
2009-11-09 14:43:07 Disabled filter flushing.
2009-11-09 14:43:07 Changed mounting to Standard
2009-11-09 14:43:07 Enabled stability checking.
2009-11-09 14:43:07 Enabled automatic sampling.
2009-11-09 14:43:07 Changed calibration points to 18
2009-11-09 16:40:39 Testing started
2009-11-09 16:41:17 Testing started
2009-11-09 16:41:35 Changed taps to 32
2009-11-09 16:41:38 Set new module configuration
2009-11-09 16:41:38 Set configuration.
2009-11-09 16:41:38 Configuration saved to flash memory
2009-11-09 16:41:46 Testing started
2009-11-09 16:42:11 Testing stopped
2009-11-09 16:42:45 Data logging started
Export

The System Log tab shows all communication between StudioPrime and the Prime module since StudioPrime was opened. Closing StudioPrime will erase the system log.

Select the <Export> button, at the bottom right of the screen, to save the system log to a text file.

5.8 Graph Tab



The graph provides a 2-axis (X,Y) plot of the measured field strength. The graph can be used to visually see hard and soft iron effects within the environment measured by the Prime module as well as corrected output after a user calibration has been performed. (The screen shot shown shows the MX and MY readings as the module was held horizontally and rotated through 360º in the horizontal plane, then held in vertical orientation and rotated 360º in the vertical plane.)

6 User Calibration

Sources of magnetic distortion that are positioned near the Prime in the user's system will distort the Earth's local magnetic field and need to be compensated for before implementing the Prime in the host system. Examples of such sources include ferrous metals and alloys (ex. iron, nickel, non-stainless steel, etc.), batteries, permanent magnets, wires, and electric motors. This compensation is accomplished by calibrating the Prime's magnetometers while mounted in the user's system. In the user's system it is expected the sources of magnetic distortion will remain fixed relative to the Prime's position. By performing a user calibration procedure, the Prime identifies these local sources of magnetic distortion and subtracts these magnetic effects from the overall reading to provide an accurate compass heading.

Additionally, the Prime's MEMS accelerometers gradually may change over time and it may be desirable to recalibrate the accelerometers from time-to-time. The accelerometer calibration procedure corrects for changes in accelerometer gain, offset, and cross axis terms. Unlike the magnetometers, the accelerometers may be calibrated outside the host system. Accelerometer calibration is more sensitive to noise or hand jitter than magnetometer calibration, especially for subsequent use at high tilt angles. Because of this, a stabilized fixture is recommended for accelerometer calibration, although resting the unit against a stable surface often is sufficient. Alternatively, the Prime can be returned to PNI for recalibration. Since change in the accelerometers is gradual and relatively small, accelerometer calibration is optional.

Key Points

1. Magnetic calibration requires incorporating the module in the user's system such that the magnetic components of the user's system can be compensated for. Full sphere coverage during calibration is ideal, but not necessary to obtain a good calibration.
2. Even though heading is only specified to a tilt angle of ≤45°, calibrating at >45° generally will improve accuracy when operating near the specification limit of 45°.
3. Accelerometer calibration requires that the module essentially be rotated through a full sphere of coverage. However, it does not require that the module be incorporated into the user's system to perform the calibration.
4. Magnetic and accelerometer calibration can be performed simultaneously. However, it may be easier to perform them separately since the requirements of each calibration are significantly different. (Magnetic calibration requires the module be incorporated in the

user's system, while accelerometer calibration requires full sphere coverage.)

5. Pay attention to the calibration scores. See Section 7.3.18 for the score meanings.

6.1 Magnetic Field Calibration Theory

The primary object of a magnetometer calibration is to compensate for distortions to the magnetic field caused by the host system. To that end, the Prime needs to be mounted within the host system and the entire application needs to be moved as a single unit during the calibration. Movement should include at least 180° of horizontal rotation (yaw), but to achieve the best accuracy a full 360° of horizontal rotation with as many different tilt angles as possible during the rotation is recommended.

6.1.1 Hard and Soft Iron Effects

Hard iron distortions are caused by permanent magnets and magnetized steel or iron objects within close proximity to the sensors. This type of distortion will remain constant and in a fixed location relative to the sensors for all heading orientations. Hard-iron distortions add a constant magnitude field component along each axis of sensor output and are compensated for by using a saturation method.

Soft-iron distortions are the result of interactions between the Earth's magnetic field and any magnetically "soft" material within close proximity to the sensors. In technical terms, soft materials have a high permeability. The permeability of a given material is a measure of how well it serves as a path for magnetic lines of force, relative to air, which has an assigned permeability of one.

The Prime 3-axis digital compass features soft-iron and hard-iron correction.

6.1.2 Pitch and Roll

The Prime uses accelerometers to measure the orientation of the compass with respect to gravity. Since the compass also measures the complete magnetic field, the Prime can correct for the tilt of the compass to provide an accurate heading.

The Prime utilizes Euler angles as the method for determining accurate orientation. This method is the same used in aircraft orientation where the outputs are Heading (Yaw), Pitch and Roll. When using Euler angles, roll is defined as the angle rotated around an axis through the center of the fuselage while pitch is rotation around an axis

through the center of the wings. These two rotations are independent of each other since the rotation axes rotate with the plane body.

For the Prime a positive pitch is when the front edge of the board is rotated upward and a positive roll is when the right edge of the board is rotated downward.

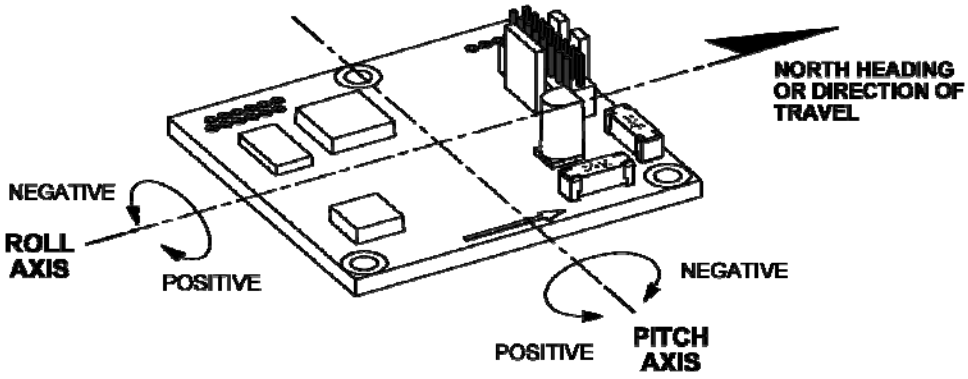


Figure 6-1: Positive & Negative Roll and Pitch Definition

6.2 Calibration Procedures

Below are instructions for performing both magnetometer and accelerometer user calibrations of the Prime module using StudioPrime and the PNI cable. All StudioPrime application functions are available through the Prime's RS232 interface, allowing this procedure to be translated into a user's imbedded solution. These calibration sequences demonstrate a good distribution of the recommended minimum sample points: additional sample points may be taken.

Once calibration is complete the "Calibration Results" window will indicate the quality of the calibration. This applies to both magnetometer and accelerometer calibration. The X, Y, and Z values show a percentage of each vector that has been covered during the calibration. For magnetometer calibration, a score of >85% is desirable for the X and Y vectors. The only way to get a Z value greater than 50% would be to take some points with the unit upside-down. For accelerometer calibration, a score of >95% is desirable for the X, Y vectors, and >90% for Z vectors. The values shown in μT for Mag Score and mg for Accel Score refer to the standard deviation of the measured samples when compared to the calculated values. The value for the Mag Score should be <0.1 and the value for the Accel Score should be <2.

With the Prime module connected and communicating with StudioPrime, go to the

Configuration tab and configure StudioPrime as follows:

- In the Filter Settings window set Taps to 32. (32 taps is recommended. Fewer taps should work, but may not give as accurate a calibration.)
- Calibration Settings: Check the Stability Checking box
- Check the Automatic Sampling box
- Set Calibration Points to at least 12 if only the magnetometers will be calibrated, and at least 18 if the accelerometers or the accelerometers & magnetometers will be calibrated. More sample points can be selected if the user desires.
- Select “Mag Only Calibration”, “Accel Only Calibration”, or “Accel and Mag Calibration”, depending on which calibration procedure will be undertaken.
- Click on the <Save> button.

Go to the Calibration tab. To perform a calibration, refer to the recommended calibration pattern given in the sections below, and then adhere to the following procedure:

- Hold the module level and stable.
- Click on the <Start> button and wait for a sample to be taken.
- Rotate the module to the next pattern position and hold the module stable until the next sample is taken.
- Repeat this until all samples, as set above, are taken.
- Click on the <Save Current User Cal> button

6.2.1 Magnetometer Only Calibration with 12 Sample Points

The following procedure is recommended for magnetic calibration. Additional sample points with the module flipped upside down are also desirable if possible.

Move the module to the following positions, noting that these are not absolute heading directs, but rather relative headings referenced to your initial heading sample. (i.e. yaw is relative to the starting orientation, and does not need to be North.)

Note: Once you begin taking calibration points, pausing between desired calibration points will cause unintentional points to be taken with auto sampling enabled.

Module approximately level

- 0° yaw
- 90° yaw
- 180° yaw
- 270° yaw

With module pitched positively ≥ 10 deg (recommended +50 degrees)

- 30° yaw with small negative roll
- 120° yaw with small positive roll
- 210° yaw with small negative roll
- 300° yaw with small positive roll

With the module pitched negatively ≥ -10 deg (recommended -50 degrees)

- 60° yaw with small positive roll
- 150° yaw with small negative roll
- 240° yaw with small positive roll
- 330° yaw with small negative roll

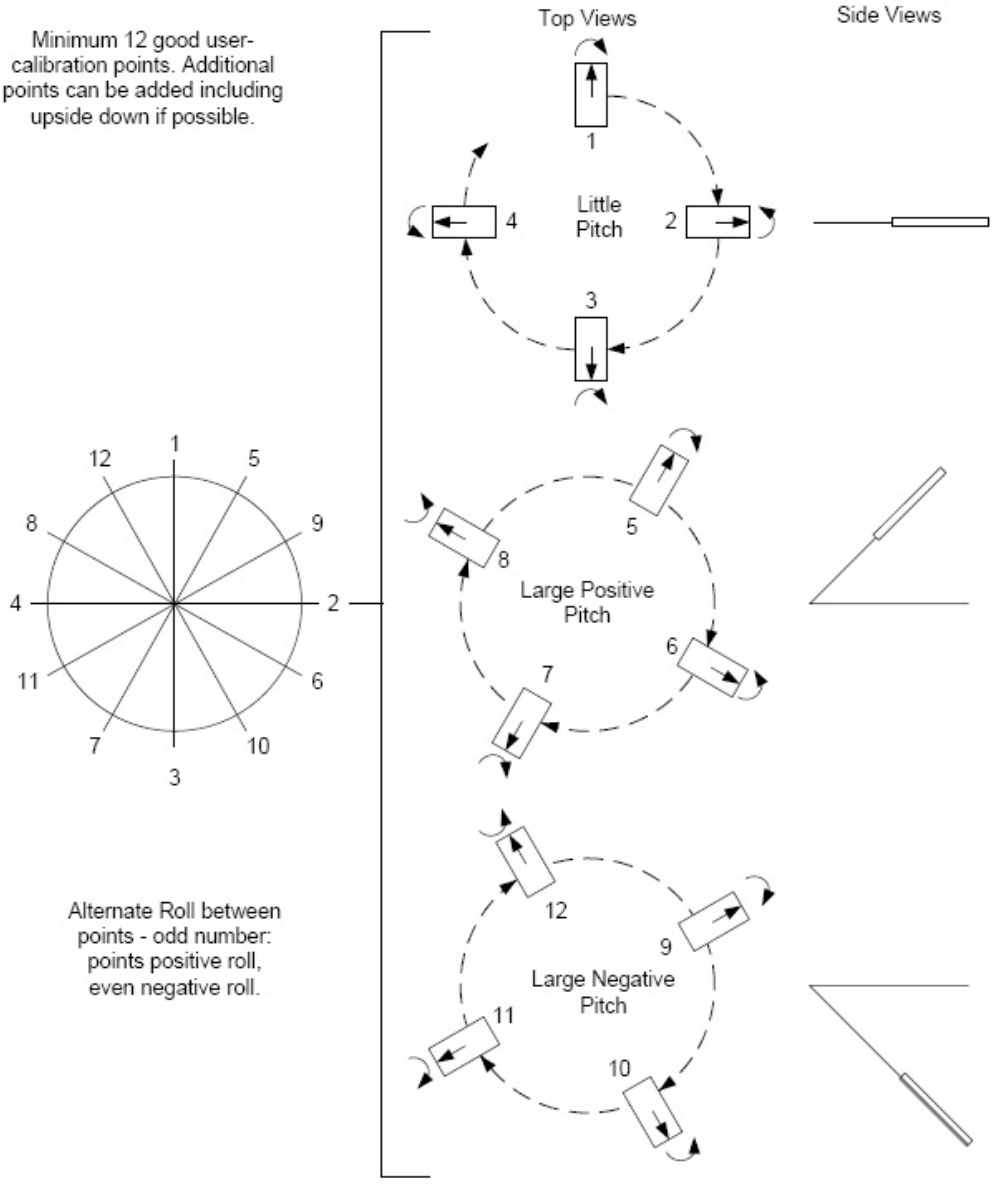

Minimum 12 good user-calibration points. Additional points can be added including upside down if possible.
Top Views
Side Views
Little Pitch
Large Positive Pitch
Large Negative Pitch
Alternate Roll between points - odd number: points positive roll, even negative roll.

Figure 6-2: Magnetometer 12 Point Calibration Pattern

6.2.2 Accelerometer Only Calibration with 18 Sample Points

The requirements for a good accelerometer calibration differ from the requirements for a good magnetometer calibration. For instance, a level yaw sweep, no matter how many points are acquired, is effectively only 1 accelerometer calibration point. PNI recommends an 18 point (or more) full range calibration pattern for the accelerometer, as described below.

- Figure 6-3 shows the two basic starting positions for the accelerometer calibration. Calibration can occur within the user's system or with the module alone. It is not necessary for the module to be placed on a hard surface as shown, but the gravitational vector (relative to the module) must be as shown. Also, the module must be held still during calibration, and holding it against a hard surface is one method to help ensure this.
- Using the module as shown on the left, rotate the module such that it sits on each of its 6 faces. Take a calibration point on each face.
- Using the module as shown on the left, rotate it 45° such that it is standing on one of its corners, as shown for the module on the right. The picture shows the module also rotated about its Z axis, but this is only for illustration purposes. Take a calibration point (0°). Now tilt the module back 45° and take another calibration point (+45°), then tilt the module forward 45° and take another calibration point (-45°). Repeat this 3-point process by holding the module on each of its 4 corners.
- Note that the 18 calibration points can be obtained in any order.

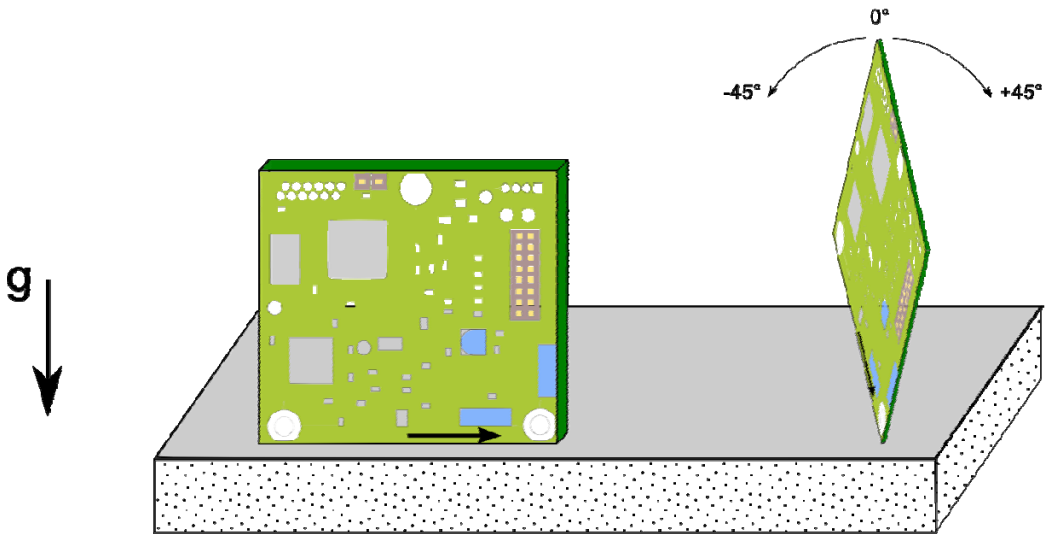


Figure 6-3: Accelerometer 18 Point Calibration Starting Positions

6.2.3 Accel and Mag Calibration

The Prime allows for a simultaneous magnetometer and accelerometer user calibration. This requires a good (full range) calibration pattern, stable measurements (not handheld), and installation in the user's system such that the appropriate local magnetic environment is present. The accelerometer calibration pattern discussed in Section 6.2.2 will work for a simultaneous calibration. Optimal performance is obtained when all rotations of the cube are performed towards magnetic north to achieve the widest possible magnetic field distribution.

Note that combining calibrations only makes sense if all the integrated system's magnetic distortions (steel structures or batteries, for instance) are present and fixed relative to the Prime when calibrating. If Accelerometer Only calibration is performed, the user's system distortions are not relevant, which allows for the Prime to be removed from the system in order to perform the Accelerometer Only calibration.

6.3 Declination Value

Declination, also called magnetic variation, is the difference between true and magnetic north, relative to a point on the earth. It is measured in degrees east or west of true north. Correcting for declination is accomplished by storing the correct declination angle, and then changing the heading reference from magnetic north to true north. Declination angles vary throughout the world, and change very slowly over time. For the greatest possible accuracy, go to the National Geophysical Data Center web page below to get the declination angle based on your latitude and longitude:

http://www.ngdc.noaa.gov/geomagmodels/Declination.jsp

6.4 Other Limitations

The Prime measures the total magnetic field within its vicinity, and this is a combination of the earth's magnetic field and local magnetic sources. The Prime can compensate for local static magnetic sources that do not exceed the dynamic range of its magnetometers. A magnetic source which is not static can create errors, and it is not possible to compensate for such a dynamic nature. In such cases, moving the Prime away from dynamic magnetic fields is recommended.

7 Operation with RS232 Interface

7.1 Datagram Structure

Transport layer for RS-232 communication:

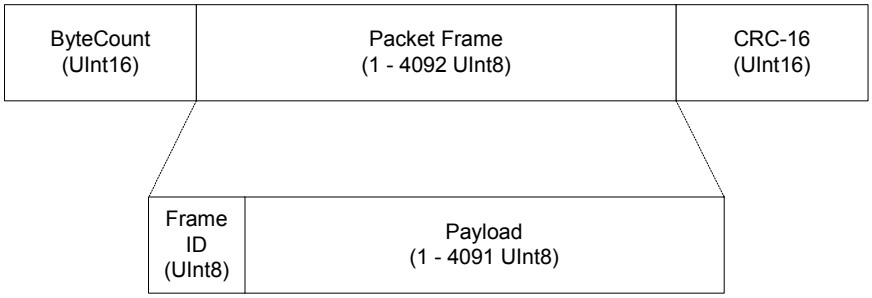


Figure 7-1: Datagram Structure

The ByteCount is the total number of bytes in the packet including the CRC-16. CRC-16 is calculated starting from the ByteCount to the last byte of the Packet Frame (see included C function at end of document). The ByteCount and CRC-16 are always transmitted in BIG ENDIAN.

7.2 Parameter Formats

Floating Point

The floating-point based parameters are in the IEEE standard format, ANSI/IEEE Std 754-1985.

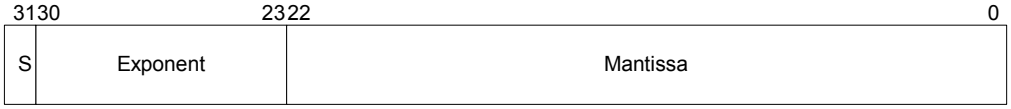
64-Bit (double precision floating point)

Shown below is the 64-bit float format in big Endian, in little Endian bytes are in reverse order in 4 byte groups (i.e.: big Endian: ABCDEFGH little Endian: DCBA HGFE).

The value (v) is determined as (if and only if 0 < Exponent < 2047): v = (-1)S * 2(Exponent-1023) * 1.Mantissa

32-Bit (single precision floating point)

Shown below is the 32-bit float format in big Endian, in little Endian all 4 bytes are in reverse order (LSB first).

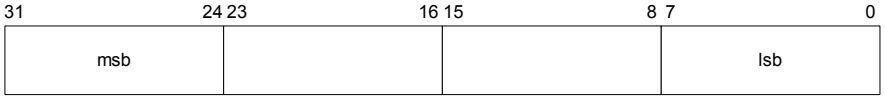


The value (v) is determined as (if and only if 0 < Exponent < 255): v = (-1)S * 2(Exponent-127) * 1.Mantissa

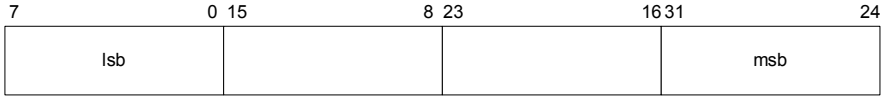
Note: Please refer to ANSI/IEEE Std 754-1985 for more information. It is also recommended that you refer to the compiler you are using on how it implements floating-point formats.

Signed 32-bit Integer (SInt32)

SInt32 based parameters are signed 32 bit numbers (2's compliment). Bit 31 represents the sign of the value (0=positive, 1=negative)



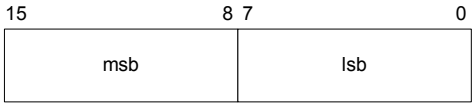
Big Endian



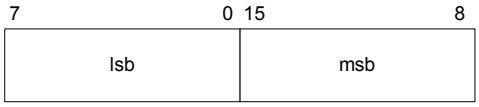
Little Endian

Signed 16-bit Integer (SInt16)

SInt16 based parameters are signed 16 bit numbers (2's compliment). Bit 15 represents the sign of the value (0=positive, 1=negative)



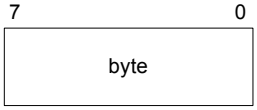
Big Endian



Little Endian

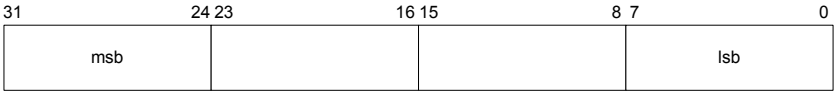
Signed 8-bit Integer (SInt8)

UInt8 based parameters are unsigned 8-bit numbers. Bit 7 represents the sign of the value (0=positive, 1=negative)

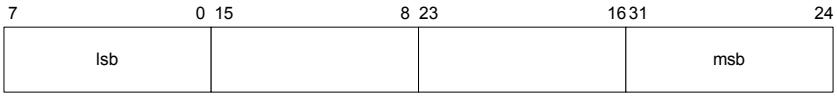


Unsigned 32-bit Integer (UInt32)

UInt32 based parameters are unsigned 32 bit numbers.



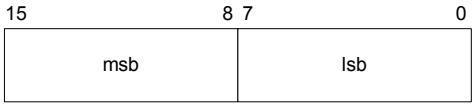
Big Endian



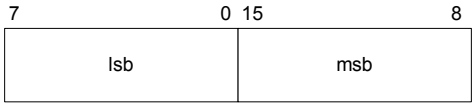
Little Endian

Unsigned 16-bit Integer (UInt16)

UInt16 based parameters are unsigned 16 bit numbers.



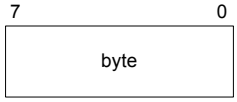
Big Endian



Little Endian

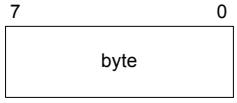
Unsigned 8-bit Integer (UInt8)

UInt8 based parameters are unsigned 8-bit numbers.



Boolean

Boolean is a 1-byte parameter that MUST have the value 0 (false) or 1 (true).



7.3 Commands & Communication Frames

The Prime's RS232 interface command set is given below in , and descriptions of each command follow in the subsequent sections.

Table 7-1: RS232 Command Set

Frame ID	Command	Description
1	kGetModInfo	Queries the modules type and firmware revision number.
2	kModInfoResp	Response to kGetModInfo
3	kSetDataComponents	Sets the data components to be output.
4	kGetData	Queries the module for data
5	kDataResp	Response to kGetData
6	kSetConfig	Sets internal configurations in the module
7	kGetConfig	Queries the module for the current internal configuration value
8	kConfigResp	Response to kGetConfig
9	kSave	Commands the module to save internal and user calibration
10	kStartCal	Commands the module to start user calibration
11	kStopCal	Commands the module to stop user calibration
12	kSetParam	Sets the FIR filter settings for the magnetometer & accelerometer sensors.
13	kGetParam	Queries for the FIR filter settings for the magnetometer & accelerometer sensors.
14	kParamResp	Contains the FIR filter settings for the magnetometer & accelerometer sensors.
15	kPowerDown	Used to completely power-down the module
16	kSaveDone	Response to kSave
17	kUserCalSampCount	Sent from the module after taking a calibration sample point
18	kUserCalScore	Contains the calibration score
19	kSetConfigDone	Response to kSetConfig
20	kSetParamDone	Response to kSetParam
21	kStartIntervalMode	Commands the module to output data at a fixed interval
22	kStopIntervalMode	Commands the module to stop data output at a fixed interval
23	kPowerUp	Sent after wake up from power down mode
24	kSetAcqParams	Sets the sensor acquisition parameters
25	kGetAcqParams	Queries for the sensor acquisition parameters
26	kAcqParamsDone	Response to kSetAcqParams
27	kAcqParamsResp	Response to kGetAcqParams
28	kPowerDownDone	Response to kPowerDown
29	kFactoryUserCal	Clears user magnetometer calibration coefficients
30	kFactorUserCalDone	Response to kFactoryUserCal
31	kTakeUserCalSample	Commands the unit to take a sample during user calibration
36	kFactoryInclCal	Clears user accelerometer calibration coefficients
37	kFactoryInclCalDone	Response to kFactoryInclCal

7.3.1 kGetModInfo (frame ID 1)

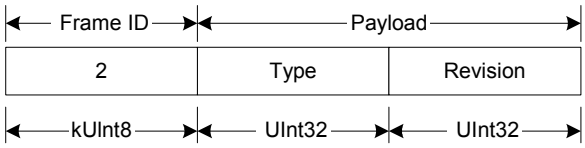
This frame queries the module's type and firmware revision number. The frame has no payload. The complete packet for the kGetModInfo command would be:

0005	01	EFD4

With: 0005 being the byte count
01 kGetModInfo command
EFD4 CRC-16 checksum

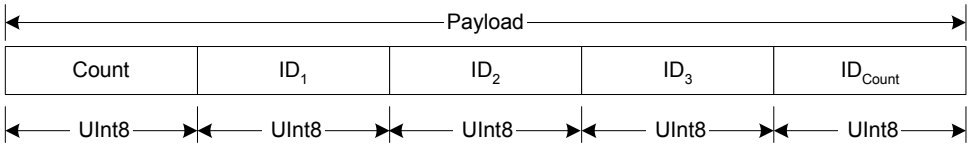
7.3.2 kModInfoResp (frame ID 2)

This frame is the response to kGetModInfo frame. The payload contains the module type identifier followed by the firmware revision number.

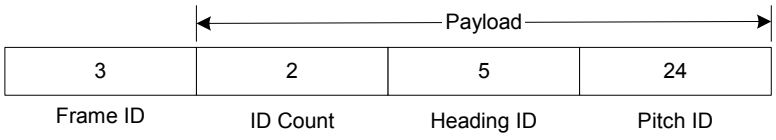


7.3.3 kSetDataComponents (frame ID 3)

This frame sets the data components in the module's data output. This is not a query for the module's data (see kGetData). The first byte of the payload indicates the number of data components followed by the data component IDs.



Example: To query the heading and pitch, the payload should contain:



When querying for data (kGetData frame), the sequence of the data component output follows the sequence of the data component IDs as set in this frame.

Table 7-2: RS232 Component Identifiers

Component	DataComponentID (decimal)	Format	Units	Range
kHeading	5	Float32	degrees	0.0˚ to 359.9˚
kDistortion	8	Boolean	True or False	False (Default) = no distortion
kCalStatus	9	Boolean	True or False	False (Default) = not calibrated
kPAligned	21	Float32	G	-1.0 to 1.0
kRAligned	22	Float32	G	-1.0 to 1.0
kIZAligned	23	Float32	G	-1.0 to 1.0
kPAngle	24	Float32	degrees	-90.0˚ to 90.0˚
kRAngle	25	Float32	degrees	-180.0˚ to 180.0˚
KXAligned	27	Float32	μT	
KYAligned	28	Float32	μT	
KZAligned	29	Float32	μT	

Component types for kSetDataComponents & kDataResp frames:

kHeading
Compass heading output.

kDistortion
Read only flag that indicates that at least one magnetometer axis reading is beyond +/- 100 μT.

kCalStatus
Read only flag that indicates user calibration status. False (Default) = Not calibrated.

kPAligned, kRAligned & kIZAligned
User calibrated Earth's acceleration vector (G) component output.

kPAngle, kRAngle
Pitch and Roll angle outputs. Pitch is equal to -90.0˚ to 90.0˚ and Roll is equal to -180.0˚ to 180.0˚.

kXAligned, kYAligned, kZAligned
User calibration Earth's magnetic field (M) vector component output.

7.3.4 kGetData (frame ID 4)

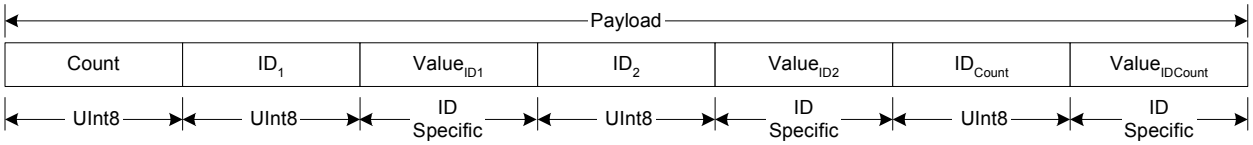
This frame queries the module for data. The frame has no payload. The complete packet for the kGetModInfo command would be:

00 05	04	BF71

with 00 05 being the byte count
04 kGetData command
BF71 CRC-16 checksum

7.3.5 kDataResp (frame ID 5)

The frame is the response to kGetData frame. The first byte of the payload indicates the number of data components then followed by the data component ID-value pairs. The sequence of the components Ids follows the sequence set in the kSetDataComponents frame.

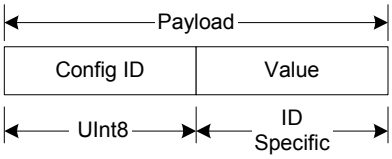


Example: If the response contains the heading and pitch, the payload would look like:

2	5	359.9	24	10.5
ID Count	Heading ID	Heading Output (Float32)	Pitch ID	Pitch Output (Float32)

7.3.6 kSetConfig (frame ID 6)

This frame sets internal configurations in the module. The first byte of the payload is the configuration ID followed by a format specific value. These configurations can only be set one at time.



Example: To configure the declination, the payload would look like:

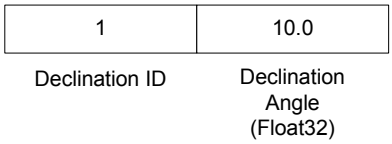


Table 7-3: RS232 Configuration Identifiers

Settings	Configuration ID	Format	Units/ Range	Default Values
kDeclination	1	Float32	-180˚ to 180˚	0˚
kTrueNorth	2	Boolean	True or False	False
kBigEndian	6	Boolean	True or False	True
kMountingRef	10	UInt8	1 = Standard 2 = X axis up 3 = Y axis up 4 = -90° heading offset 5 = -180° heading offset 6 = -270° heading offset 7 = Z down 8 = X + 90° 9 = X + 180° 10 = X + 270° 11 = Y + 90° 12 = Y + 180° 13 = Y + 270° 14 = Z down + 90° 15 = Z down + 180° 16 = Z down + 270° 17 = X down 18 = X down +90 19 = X down +180 20 = X down +270 21 = Y down 22 = Y down +90 23 = Y down +180 24 = Y down + 270	1
kUserCalStableCheck	11	Boolean	True or False	True
kUserCalNumPoints	12	UInt32	12 – 50	12
kUserCalAutoSampling	13	Boolean	True or False	True

kBaudRate	14	UInt8	0 – 300 1 – 600 2 – 1200 3 – 1800 4 – 2400 5 – 3600 6 – 4800 7 – 7200 8 – 9600 9 – 14400 10 – 19200 11 – 28800 12 – 38400 13 – 57600 14 - 115200	12

Configuration parameters and settings for kSetConfig:

kDeclination

This sets the declination angle to determine True North heading. Positive declination is easterly declination and negative is westerly declination. This is not applied until kTrueNorth is set to true.

kTrueNorth

Flag to set compass heading output to true north heading by adding the declination angle to the magnetic north heading.

kBigEndian

Flag to set the Endianness of packets

kMountingRef

This sets the reference orientation for the module:

Standard: When selected the unit is to be mounted with the main board in a horizontal position (the Z axis magnetic sensor is vertical).

X Sensor Up: When selected the unit is to be mounted with the main board in a vertical position: the X axis magnetic sensor is vertical and points up.

Y Sensor Up: When selected the unit is to be mounted with the main board in a vertical position: the Y axis magnetic sensor is vertical and points up.

X Sensor Down: When selected the unit is to be mounted with the main board in a vertical position: the X axis magnetic sensor is vertical and points down.

Y Sensor Down: When selected the unit is to be mounted with the main board in a vertical position: the Y axis magnetic sensor is vertical and points down.

Standard 90 Degrees: When selected the unit is to be mounted with the main board in a horizontal position but rotated so the arrow is pointed 90 degrees counterclockwise to the front of the host system.

Standard 180 Degrees: When selected the unit is to be mounted with the main board in a horizontal position but rotated so the arrow is pointed 180 degrees counterclockwise to the front of the host system.

Standard 270 Degrees: When selected the unit is to be mounted with the main board in a horizontal position but rotated so the arrow is pointed 270 degrees counterclockwise to the front of the host system.

kUserCalStableCheck

This flag is used during user calibration. If set to FALSE, the module will take a point if the magnetic field has changed more than 23 µT in either axis. If set to TRUE the unit will take a point if the magnetic field has a stability of 30µT in each direction and the previous point changed more than 5µT and acceleration vector delta within 2 mg.

kUserCalNumPoints

The maximum number samples taken during user calibration.

kUserCalAutoSampling

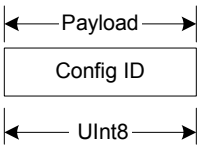
This flag is used during user calibration. If set to TRUE, the module continuously takes calibration sample points until the set number of calibration samples. If set to FALSE, the module waits for kTakeUserCalSample frame to take a sample with the condition that a magnetic field vector component delta is greater than 5 micro Tesla from the last sample point.

kBaudRate

Baud rate index value. A power-down power-up cycle is required when changing the baud rate.

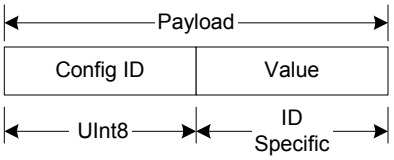
7.3.7 kGetConfig (frame ID 7)

This frame queries the module for the current internal configuration value. The payload contains the configuration ID requested.

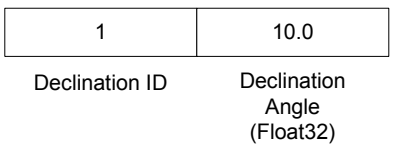


7.3.8 kConfigResp (frame ID 8)

This frame is the response to kGetConfig frame. The payload contains the configuration ID and value.



Example: If a request to get the set declination angle, the payload would look like:

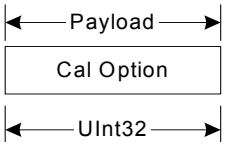


7.3.9 kSave (frame ID 9)

This frame commands the module to save internal configurations and user calibration to non-volatile memory. Internal configurations and user calibration is restored on power up. The frame has no payload. This is the ONLY command that causes the module to save information into non-volatile memory.

7.3.10 kStartCal (frame ID 10)

This frame commands the module to start user calibration with the current sensor acquisition parameters, internal configurations and FIR filter settings.



Calibration option values: 0 = Magnetometer Only Calibration
100 = Accelerometer Only Calibration
110 = Accel and Mag Calibration

7.3.11 kStopCal (frame ID 11)

This frame commands the module to stop calibration points sampling and calculate the calibration score and coefficients.

7.3.12 kSetParam (frame ID 12)

This frame sets the FIR filter settings for the magnetometer and accelerometer sensors. The second byte of the payload indicates the x vector component of either the magnetometer or accelerometer. This is to differentiate whether to apply the filter settings to the magnetometer or accelerometer. The third byte in the payload indicates the number of FIR taps to use then followed by the filter taps. Each tap is a Float64. The maximum number of taps that can be set is 32 and the minimum is 0 (no filtering). Parameter ID should be set to 3.

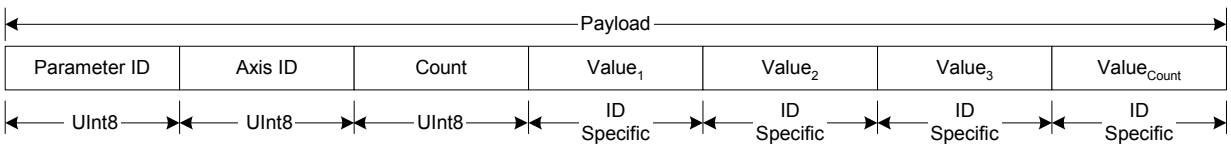
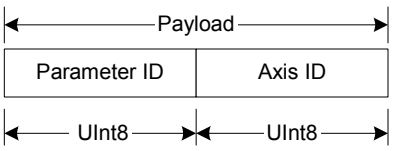


Table 7-4: Recommended FIR Filter Tap Values

Count	4 Tap Filter	8 Tap Filter	16 Tap Filter	32 Tap Filter
1	04.6708657655334e-2	01.9875512449729e-2	07.9724971069144e-3	01.4823725958818e-3
2	04.5329134234467e-1	06.4500864832660e-2	01.2710056429342e-2	02.0737124095482e-3
3	04.5329134234467e-1	01.6637325898141e-1	02.5971390034516e-2	03.2757326624196e-3
4	04.6708657655334e-2	02.4925036373620e-1	04.6451949792704e-2	05.3097803863757e-3
5		02.4925036373620e-1	07.1024151197772e-2	08.3414139286254e-3
6		01.6637325898141e-1	09.5354386848804e-2	01.2456836057785e-2
7		06.4500864832660e-2	01.1484431942626e-1	01.7646051430536e-2
8		01.9875512449729e-2	01.2567124916369e-1	02.3794805168613e-2
9			01.2567124916369e-1	03.0686505921968e-2
10			01.1484431942626e-1	03.8014333463472e-2
11			09.5354386848804e-2	04.5402682509802e-2
12			07.1024151197772e-2	05.2436112653103e-2
13			04.6451949792704e-2	05.8693165018301e-2
14			02.5971390034516e-2	06.3781858267530e-2
15			01.2710056429342e-2	06.7373451424187e-2
16			07.9724971069144e-3	06.9231186101853e-2
17				06.9231186101853e-2
18				06.7373451424187e-2
19				06.3781858267530e-2
20				05.8693165018301e-2
21				05.2436112653103e-2
22				04.5402682509802e-2
23				03.8014333463472e-2
24				03.0686505921968e-2
25				02.3794805168613e-2
26				01.7646051430536e-2
27				01.2456836057785e-2
28				08.3414139286254e-3
29				05.3097803863757e-3
30				03.2757326624196e-3
31				02.0737124095482e-3
32				01.4823725958818e-3

7.3.13 kGetParam (frame ID 13)

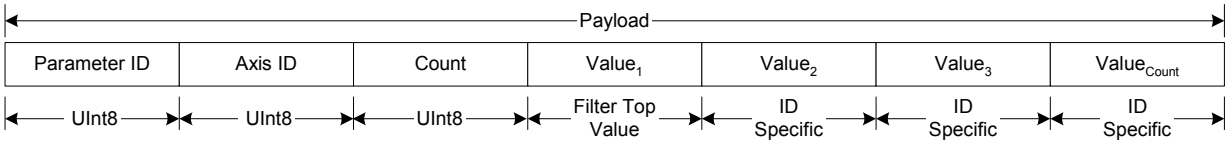
This frame queries the FIR filter settings for the magnetometer and accelerometer sensors. The first byte is the kFIRConfig ID followed by the vector axis ID byte.



Axis IDs: kXAxis = 1
kYAxis = 2
kZAxis = 3
kPAxis = 4
kRAxis = 5
kIZAxis = 6

7.3.14 kParamResp (frame ID 14)

This frame contains the current FIR filter settings for either magnetometer or accelerometer sensors. The second byte of the payload is the vector axis ID, the third byte is the number of filter taps then followed by the filter taps. Each tap is a Float64.

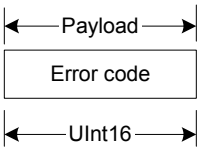


7.3.15 kPowerDown (frame ID 15)

This frame is used to completely power-down the module. The frame has no payload. The unit will power down all peripherals including the RS-232 driver but the driver chip has the feature to keep the Rx line enabled. Any character sent to the module causes it to exit power down mode. It is recommended to send the byte oxFFh.

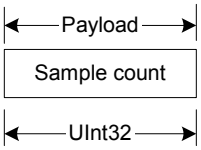
7.3.16 kSaveDone (frame ID 16)

This frame is the response to kSave frame. The payload contains a UInt16 error code, 0000h indicates no error, 0001h indicates error when attempting to save data into non-volatile memory.



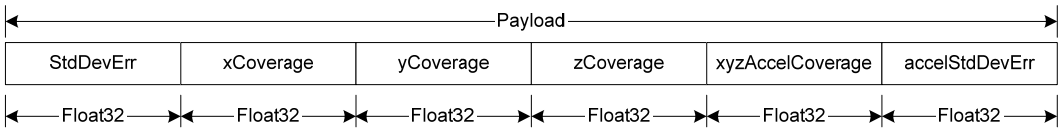
7.3.17 kUserCalSampCount (frame ID 17)

This frame is sent from the module after taking a calibration sample point. The payload contains the sample count with the range of 1 to 32



7.3.18 kUserCalScore (frame ID 18)

This frame contains the calibration score, which is a series of Float32 values: stdDevErr, xCoverage, yCoverage, zCoverage, xyzAccelCoverage, accelStdDevErr. If a kStopCal command is sent before 12 points have been acquired (calibration is aborted), values that were to be updated will be set to -1 except for xyzAccelCoverage, which will be -101.01. Values for parameters that were not being updated will reflect the last calibration values. For example, if a Mag Only Calibration is stopped before 12 samples are taken, the StdDevErr, xCoverage, yCoverage, and zCoverage will all report -1, while the xyzAccelCoverage and accelStdDevErr will report values from the last successful accelerometer calibration.



StdDevErr : The compass samples magnetic field standard deviation error.
xCoverage : Percentage of how much of the X magnetometer axis was covered by the sampling.
yCoverage : Percentage of how much of the Y magnetometer axis was covered by the sampling.
zCoverage : Percentage of how much of the Z magnetometer axis was covered by the sampling.
xyzAccelCoverage : Percentage of how much of the accelerometer axes were covered by the sampling formatted as XXYY.ZZ. XX is the X axis coverage, YY is the Y axis coverage and ZZ is the Z axis coverage. For example xyzAccelCoverage = 8590.67 means accelerometer X coverage is 85%, Y coverage is 90% and Z coverage is 67%.
accelStdDevErr : The accelerometer samples' field standard deviation error.

7.3.19 kSetConfigDone (frame ID 19)

This frame is the response to kSetConfig frame. The frame has no payload.

7.3.20 kSetParamDone (frame ID 20)

This frame is the response to kSetParam frame. The frame has no payload.

7.3.21 kStartIntervalMode (frame ID 21)

The frame commands the module to output data (push mode) at a fixed time interval (See kSetAcqParams). The frame has no payload.

7.3.22 kStopIntervalMode (frame ID 22)

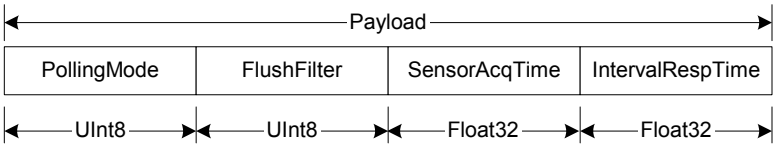
This frame commands the module to stop data output at a fixed time interval. The frame has no payload.

7.3.23 kPowerUp (frame ID 23)

This frame is sent from the module after wake up from power down mode. The frame has no payload. Since the module was previously powered down which drives the RS-232 driver TX line low (break signal), it is recommended to disregard the first byte.

7.3.24 kSetAcqParams (frame ID 24)

This frame sets the sensor acquisition parameters in the unit. The payload should contain the following:



PollingMode:
Flag to set push/poll data output mode. Default is TRUE (poll mode).

FlushFilter:
Flag to set FIR filter flushing every sample. Default is FALSE (no flushing).

SensorAcqTime:
The internal time interval between sensor acquisitions. Default is 0.0 seconds, this means that the module will reacquire immediately right after the last acquisition.

IntervalRespTime:
The time interval the module output data in push mode. Default is 0.0 seconds, this means that the module will push data out immediately after an acquisition cycle.

7.3.25 kGetAcqParams (frame ID 25)

This frame queries the unit for acquisition parameters. The frame has no payload.

7.3.26 kAcqParamsDone (frame ID 26)

This frame is the response to kSetAcqParams frame. The frame has no payload.

7.3.27 kAcqParamsResp (frame ID 27)

This frame is the response to kGetAcqParams frame. The payload should contain the same payload as the kSetAcqParams frame.

7.3.28 kPowerDownDone (frame ID 28)

This frame is the response to kPowerDown frame. This indicates that the unit successfully received the kPowerDone frame and is in the process of powering down. The frame has no payload.

7.3.29 kFactoryUserCal (frame ID 29)

This frame clears the user magnetometer calibration coefficients. The frame has no payload. This frame must be followed by the kSave frame to change in non-volatile memory.

7.3.30 kFactoryUserCalDone (frame ID 30)

This frame is the response to kFactoryUserCal frame. The frame has no payload.

7.3.31 kTakeUserCalSample (frame ID 31)

This frame commands the unit to take a sample during user calibration. The frame has no payload.

7.3.32 kFactoryInclCal (frame ID 36)

This frame clears the user accelerometer calibration coefficients. The frame has no payload. This frame must be followed by the kSave frame to change in non-volatile memory.

7.3.33 kFactoryInclCalDone (frame ID 37)

This frame is the response to kFactoryInclCal frame. The frame has no payload.

7.4 Code Examples

The following example files (CommProtocol.h, CommProtocol.cp, Prime.h and Prime.cp) would be used together for proper communication with a Prime module.

NOTE: The user also needs to create the following: SystemSerPort.h; Processes.h, TickGenerator.h.

7.4.1 Header File & CRC-16 Function

```
// type declarations
typedef struct
{
   UInt8 pollingMode, flushFilter;
   Float32 sensorAcqTime, intervalRespTime;
} __attribute__ ((packed)) AcqParams;

typedef struct
{
   Float32 stdDevErr;
   Float32 xCoverage;
   Float32 yCoverage;
   Float32 zCoverage;
   Float32 xyzAccelCoverage;
   Float32 accelStdDevErr;
} __attribute__ ((packed)) CalScore;

enum
{
   // Frame IDs (Commands)
   kGetModInfo = 1,        // 1
   kModInfoResp,           // 2
   kSetDataComponents,     // 3
   kGetData,               // 4
   kDataResp,              // 5
   kSetConfig,             // 6
   kGetConfig,             // 7
   kConfigResp,            // 8
   kSave,                  // 9
   kStartCal,              // 10
   kStopCal,               // 11
   kSetParam,              // 12
   kGetParam,              // 13
   kParamResp,             // 14
   kPowerDown,             // 15
   kSaveDone,              // 16
   kUserCalSampCount,      // 17
   kUserCalScore,          // 18
   kSetConfigDone,         // 19
   kSetParamDone,          // 20
   kStartIntervalMode,     // 21
   kStopIntervalMode,      // 22
   kPowerUp,               // 23
   kSetAcqParams,          // 24
   kGetAcqParams,          // 25
   kAcqParamsDone,         // 26
   kAcqParamsResp,         // 27
   kPowerDoneDown,         // 28
   kFactoryUserCal,        // 29
```

```
   kFactoryUserCalDone,   // 30
   kTakeUserCalSample,    // 31
   kFactoryInclCal,       // 36
   kFactoryInclCalDone,   // 37

   // Param IDs
   kFIRConfig = 1,//3-AxisID(UInt8)+
                  //Count(UInt8)+Value(Float64)+...

   // Data Component IDs
   kHeading = 5,          // 5 - type Float32
   kDistortion = 8,       // 8 - type boolean
   kPAligned = 21,        // 21 - type Float32
   kRAligned,             // 22 - type Float32
   kIZAligned,            // 23 - type Float32
   kPAngle,               // 24 - type Float32
   kRAngle,               // 25 - type Float32
   kXAligned = 27,        // 27 - type Float32
   kYAligned,             // 28 - type Float32
   kZAligned,             // 29 - type Float32

   // Configuration Parameter IDs
   kDeclination = 1,      // 1 - type Float32
   kTrueNorth,            // 2 - type boolean
   kMountingRef = 10,     // 10 - type UInt8
   kUserCalStableCheck,   // 11 - type boolean
   kUserCalNumPoints,     // 12 - type UInt32
   kUserCalAutoSampling,  // 13 - type boolean
   kBaudRate,             // 14 - UInt8

   // Mounting Reference IDs
   kMountedStandard = 1,  // 1
   kMountedXUp,           // 2
   kMountedYUp,           // 3
   kMountedStdPlus90,     // 4
   kMountedStdPlus180,    // 5
   kMountedStdPlus270,    // 6

   // Result IDs
   kErrNone = 0,          // 0
   kErrSave,              // 1
};

// function to calculate CRC-16
UInt16 CRC(void * data, UInt32 len)
{
   UInt8 * dataPtr = (UInt8 *)data;
   UInt32 index = 0;
   // Update the CRC for transmitted and received data using
   // the CCITT 16bit algorithm (X^16 + X^12 + X^5 + 1).
   UInt16 crc = 0;
   while(len--)
   {
         crc = (unsigned char)(crc >> 8) | (crc << 8);
         crc ^= dataPtr[index++];
         crc ^= (unsigned char)(crc & 0xff) >> 4;
         crc ^= (crc << 8) << 4;
         crc ^= ((crc & 0xff) << 4) << 1;
   }
   return crc;
}
```

7.4.2 CommProtocol.h File

Note: This file contains objects used to handle the serial communication with the unit. Unfortunately, these files are not available as the program was written on a non-PC computer. The comments in the code should explain what is expected to be sent or received from these functions so that you can write this section for your specific platform. For example, with the TickGenerator.h, you would need to write a routing that generates 10msec ticks.

```
#pragma once

#include "SystemSerPort.h"
#include "Processes.h"


//
//CommHandler is a base class that provides a callback for
//incoming messages.
//
class CommHandler
{
   public:
         // Call back to be implemented in derived class.
         virtual void HandleComm(UInt8 frameType, void * dataPtr =
NULL, UInt16 dataLen = 0) {}
};

//
//CommProtocol handles actual serial communication with the unit.
//Process is a base class that provides CommProtocol with
//cooperative parallel processing.  The Control method will be
//called by a process manager on a continuous basis.
//
class CommProtocol : public Process
{
   public:
         enum
         {
               // Frame IDs (Commands)
               kGetModInfo = 1,        // 1
               kModInfoResp,           // 2
               kSetDataComponents,     // 3
               kGetData,               // 4
               kDataResp,              // 5

               // Data Component IDs

               kHeading = 5,           // 5 - type Float32
               kPAligned = 21,         // 21 - type Float32
               kRAligned,              // 22 - type Float32
               kIZAligned,             // 23 - type Float32
               kPAngle,                // 24 - type Float32
               kRAngle,                // 25 - type Float32
         };


         enum
         {
```

```
                //maximum size of our input buffer
                kBufferSize = 512,

                //minimum size of a serial packet
                kPacketMinSize = 5
            };

            //SerPort is a serial communication object abstracting
            //the hardware implementation
            CommProtocol(CommHandler * handler = NULL, SerPort *
serPort = NULL);

            void Init(UInt32 baud = 38400);

            void SendData(UInt8 frame, void * dataPtr = NULL, UInt32
len = 0);
            void SetBaud(UInt32 baud);

      protected:
            CommHandler * mHandler;
            SerPort * mSerialPort;

            UInt8 mOutData[kBufferSize], mInData[kBufferSize];
            UInt16 mExpectedLen;
            UInt32 mOutLen, mOldInLen, mTime, mStep;

            UInt16 CRC(void * data, UInt32 len);
            void Control();
   };
```

7.4.3 CommProtocol.cp File

```
   #include "CommProtocol.h"

   // import an object that will provide a 10mSec tick count through
   // a function called Ticks()
   #include "TickGenerator.h"


   //
   //  SerPort is an object that controls the physical serial
   // interface.  It handles sending out the characters, and buffers
   // the characters read in until we are ready for them.
   //
   CommProtocol::CommProtocol(CommHandler   *   handler,   SerPort   *
serPort)
    : Process("CommProtocol")
   {
   // store the object that will parse the data when it is fully
   // received
      mHandler = handler;
      mSerialPort = serPort;
      Init();
   }

   //
   // Initialize the serial port and variables that will control
   // this process
   //
   void CommProtocol::Init(UInt32 baud)
   {
      SetBaud(baud);
      mOldInLen = 0;          // no data previously received

      mStep = 1;              // goto the first step of our process
   }

   //
   //  Put together the frame to send to the unit
   //
   void  CommProtocol::SendData(UInt8  frameType,  void  *  dataPtr,
UInt32 len)
   {
      UInt8 * data = (UInt8 *)dataPtr;  // the data to send
      UInt32 index = 0;       // our location in the frame we are
                              // putting together
      UInt16 crc;       // the CRC to add to the end of the packet
      UInt16 count;     // the total length the packet will be

      count = (UInt16)len + kPacketMinSize;

      // exit without sending if there is too much data to fit
      // inside our packet
      if(len > kBufferSize - kPacketMinSize) return;

      // Store the total len of the packet including the len
      // bytes(2), the frame ID(1), the data (len), and the crc (2).
      // If no data is sent, the min len is 5
      mOutData[index++] = count >> 8;
      mOutData[index++] = count & 0xFF;
```

```
   // store the frame ID
   mOutData[index++] = frameType ;

   // copy the data to be sent
   while(len--) mOutData[index++] = *data++;

   // compute and add the crc
   crc = CRC(mOutData, index);
   mOutData[index++] = crc >> 8 ;
   mOutData[index++] = crc & 0xFF ;

   // Write block will copy and send the data out the serial port
   mSerialPort->WriteBlock(mOutData, index);
}



//
// Call the functions in serial port necessary to change the
// baud rate
//
void CommProtocol::SetBaud(UInt32 baud)
{
   mSerialPort->SetBaudRate(baud);

   // clear any data that was already waiting in the buffer
   mSerialPort->InClear();
}

//
// Update the CRC for transmitted and received data using the
// CCITT 16bit algorithm (X^16 + X^12 + X^5 + 1).
//
UInt16 CommProtocol::CRC(void * data, UInt32 len)
{
   UInt8 * dataPtr = (UInt8 *)data;
   UInt32 index = 0;

   UInt16 crc = 0;
   while(len--)
   {
         crc = (unsigned char)(crc >> 8) | (crc << 8);
         crc ^= dataPtr[index++];
         crc ^= (unsigned char)(crc & 0xff) >> 4;
         crc ^= (crc << 8) << 4;
         crc ^= ((crc & 0xff) << 4) << 1;
   }
   return crc;
}

//
//  This is called each time this process gets a turn to execute.
//
void CommProtocol::Control()
{
   // InLen returns the number of bytes in the input buffer of
   // the serial object that are available for us to read.
   UInt32 inLen = mSerialPort->InLen();

   switch(mStep)
```

```
{
	case 1:
	{
		// wait for length bytes to be received by the
		// serial object
		if(inLen >= 2)
		{
			// Read block will return the number of
			// requested (or available) bytes that are in
			// the serial objects input buffer.
			// read the byte count
			mSerialPort->ReadBlock(mInData, 2);

			// byte count is ALWAYS transmitted in big
			// endian, copy byte count to mExpectedLen to
			// native endianess
			mExpectedLen =
				(mInData[0] << 8) | mInData[1];

			// Ticks is a timer function.  1 tick =
			// 10msec.
			// wait up to 1/2s for the complete frame
			// (mExpectedLen) to be received
			mTime = Ticks() + 50 ;
			mStep++ ;  //go to next step in the process
		}
		break ;
	}

	case 2:
	{
		// wait for msg complete or timeout
		if(inLen >= mExpectedLen - 2)
		{
			// calculated and received crcs.
			UInt16 crc, crcReceived;

			// Read block will return the number of
			// requested (or available) bytes that are in
			// the serial objects input buffer.
			mSerialPort->ReadBlock(&mInData[2],
						mExpectedLen - 2);
			// in CRC verification, don't include the CRC
			// in the recalculation (-2)
			crc = CRC(mInData, mExpectedLen - 2);
			// CRC is also ALWAYS transmitted in big
			// endian
			crcReceived = (mInData[mExpectedLen - 2]
				<< 8) | mInData[mExpectedLen - 1] ;

			if(crc == crcReceived)
			{
				//  the  crc  is  correct,  so  pass  the
frame
				// up for processing.
				if(mHandler)
					mHandler->HandleComm(mInData[2],
						&mInData[3], mExpectedLen -
							kPacketMinSize);
			}
			else
```

```
                        {
                              //   crc's   don't   match   so   clear
everything
                              //  that  is  currently  in  the  input
   buffer
                              // since the data is not reliable.
                              mSerialPort->InClear();
                        }

                        // go back to looking for the length bytes.
                        mStep = 1 ;
                  }
                  else
                  {
                        //Ticks is a timer function. 1 tick = 10msec.
                        if(Ticks() > mTime)
                        {
                              // Corrupted message.  We did not get
                              // the length we were expecting within
                              //  1/2sec  of  receiving  the  length
   bytes.
                              // Clear everything in the input buffer
                              // since the data is unreliable
                              mSerialPort->InClear();

                              // Look for the next length bytes
                              mStep = 1 ;
                        }
                  }
                  break ;
            }

            default:
                  break ;
      }
   }
```

7.4.4 Prime.h File

```
#pragma once

#include "Processes.h"
#include "CommProtocol.h"


//
// This file contains the object providing communication to the
// Prime.  It will set up the unit and parse packets received
// Process is a base class that provides Prime with cooperative
// parallel processing.  The Control method will be
// called by a process manager on a continuous basis.
//
class Prime : public Process, public CommHandler
{
   public:
         Prime(SerPort * serPort);
         ~Prime();

   protected:
         CommProtocol * mComm;

         UInt32 mStep, mTime, mResponseTime;

         void HandleComm(UInt8 frameType, void * dataPtr = NULL,
UInt16 dataLen = 0);
         void SendComm(UInt8 frameType, void * dataPtr = NULL,
UInt16 dataLen = 0);

         void Control();
};
```

7.4.5 Prime.cp File

```
#include "Prime.h"
#include "TickGenerator.h"

const UInt8 kDataCount = 4;// We will be requesting 4 components
                           //(Heading, pitch, roll, temperature)
//
//  This object polls the Prime unit once a second for heading,
// pitch, roll and temperature.
//

Prime::Prime(SerPort * serPort)
 : Process("Prime")
{
   // Let the CommProtocol know this object will handle any
   // serial data returned by the unit
   mComm = new CommProtocol(this, serPort);

   mTime = 0;
   mStep = 1;
}

Prime::~Prime()
{
}

//
// Called by the CommProtocol object when a frame is completely
// received
//
void Prime::HandleComm(UInt8 frameType, void * dataPtr,
                                                  UInt16 dataLen)
{
   UInt8 * data = (UInt8 *)dataPtr;

   switch(frameType)
   {
         case CommProtocol::kDataResp:
         {
               // Parse the data response
               UInt8 count = data[0]; // The number of data
                                      // elements returned
               UInt32 pntr = 1;       // Used to retrieve the
                                      // returned elements

               // The data elements we requested
               Float32 heading, pitch, roll, temperature;

               if(count != kDataCount)
               {
                     // Message is a function that displays a C
                     // formatted string (similar to printf)
                     Message("Received %u data elements instead of
                           the %u requested\r\n", (UInt16)count,
                      (UInt16)kDataCount);
                     return;
               }
```

```
// loop through and collect the elements
while(count)
{
      // The elements are received as {type (ie.
      // kHeading), data}
      switch(data[pntr++])   // read the type and
                             // go to the first
                             // byte of the data
      {
            // Only handling the 4 elements we are
            // looking for
            case CommProtocol::kHeading:
            {
                  // Move(source, destination, size
                  // (bytes)).  Move copies the
                  // specified number of bytes from
                  // the source pointer to the
                  // destination pointer.
                  // Store the heading.
                  Move(&(data[pntr]), &heading,
                                    sizeof(heading));

                  // increase the pointer to point
                  // to the next data element type
                  pntr += sizeof(heading);
                  break;
            }

            case CommProtocol::kPAngle:
            {
                  // Move(source, destination, size
                  // (bytes)).  Move copies the
                  // specified number of bytes from
                  // the source pointer to the
                  // destination pointer.
                  // Store the pitch.
                  Move(&(data[pntr]), &pitch,
                                    sizeof(pitch));

                  // increase the pointer to point
                  // to the next data element type
                  pntr += sizeof(pitch);
                  break;
            }

            case CommProtocol::kRAngle:
            {
                  // Move(source, destination, size
                  // (bytes)).  Move copies the
                  // specified number of bytes from
                  // the source pointer to the
                  // destination pointer.
                  // Store the roll.
                  Move(&(data[pntr]), &roll,
                                    sizeof(roll));

                  // increase the pointer to point
                  // to the next data element type
                  pntr += sizeof(roll);
                  break;
            }
```

```
                              case CommProtocol::kTemperature:
                              {
                                    // Move(source, destination, size
                                    // (bytes)).  Move copies the
                                    // specified number of bytes from
                                    // the source pointer to the
                                    // destination pointer.
                                    // Store the heading.
                                    Move(&(data[pntr]), &temperature,
                                                sizeof(temperature));

                                    // increase the pointer to point
                                    // to the next data element type
                                    pntr += sizeof(temperature);
                                    break;
                              }

                              default:
                                    // Message is a function that
                                    // displays a formatted string
                                    // (similar to printf)
                                    Message("Unknown type: %02X\r\n",
                                                      data[pntr - 1]);
                                    // unknown data type, so size is
                                    // unknown, so skip everything
                                    return;
                                    break;
                        }

                        count--;    // One less element to read in
                  }

                  // Message is a function that displays a formatted
                  // string (similar to printf)
                  Message("Heading: %f, Pitch: %f, Roll: %f,
                        Temperature: %f\r\n", heading, pitch, roll,
                                                temperature);
                  mStep--;          // send next data request
                  break;
            }

            default:
            {
                  // Message is a function that displays a formatted
                  // string (similar to printf)
                  Message("Unknown frame %02X received\r\n",
                                    (UInt16)frameType);
                  break;
            }
      }
   }

   //
   //  Have the CommProtocol build and send the frame to the unit.
   //
   void  Prime::SendComm(UInt8  frameType,  void  *  dataPtr,  UInt16
dataLen)
   {
      if(mComm) mComm->SendData(frameType, dataPtr, dataLen);
      // Ticks is a timer function.  1 tick = 10msec.
```

```
   mResponseTime = Ticks() + 300;     // Expect a response within
                                      // 3 seconds
}

//  This is called each time this process gets a turn to execute.
//
void Prime::Control()
{
   switch(mStep)
   {
         case 1:
         {
               // the compents we are requesting, preceded by the
               // number of...
               UInt8 pkt[kDataCount + 1];
               // ...components being requested

               pkt[0] = kDataCount;
               pkt[1] = CommProtocol::kHeading;
               pkt[2] = CommProtocol::kPAngle;
               pkt[3] = CommProtocol::kRAngle;

               SendComm(CommProtocol::kSetDataComponents,
                                    pkt, kDataCount + 1);

               // Ticks is a timer function.  1 tick = 10msec.
               mTime = Ticks() + 100; // Taking a sample in 1s.
               mStep++;          // go to next step of process
               break;
         }
```

```
        case 2:
        {
              // Ticks is a timer function.  1 tick = 10msec.
              if(Ticks() > mTime)
              {
                    // tell the unit to take a sample
                    SendComm(CommProtocol::kGetData);
                    mTime = Ticks() + 100; // take a sample every
                                           // second
                    mStep++;
              }
              break;
        }

        case 3:
        {
              // Ticks is a timer function.  1 tick = 10msec.
              if(Ticks() > mResponseTime)
              {
                    Message("No response from the unit.  Check
                                connection and try again\r\n");
                    mStep = 0;
              }
              break;
        }

        default:
              break;
   }
}
```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